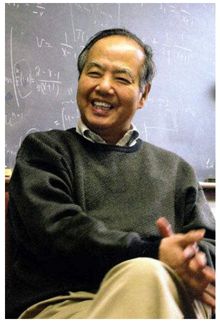
Summary of Mini-Workshop on Anomalies at the LHC



Bruce Mellado

University of the Witwatersrand and iThemba LABS

INSTITUTE FOR COLLIDER PARTICLE PHYSICS

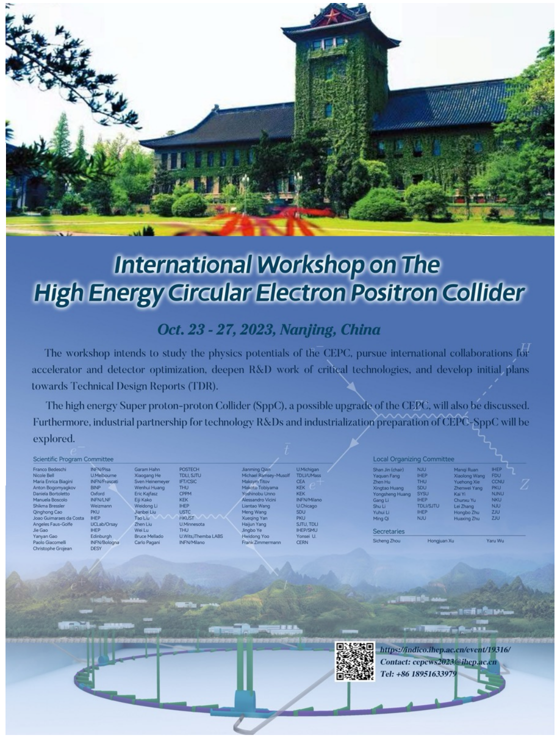
UNIVERSITY OF THE WITWATERSRAND

NRF National Research Foundation

iThemba LABS Laboratory for Accelerator Based Sciences

南京大學

NANJING UNIVERSITY



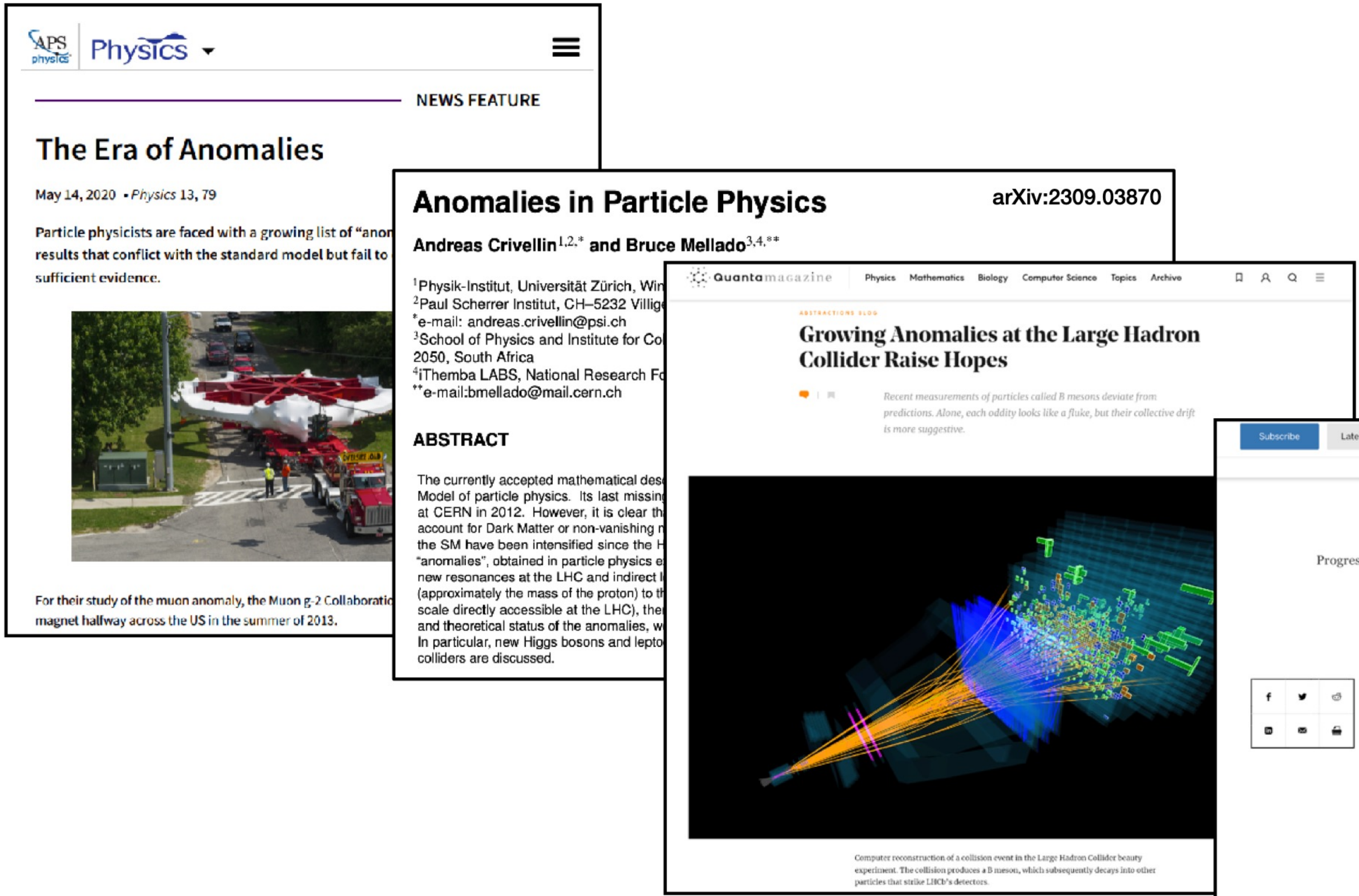
CEPC2023, Nanjing, 27/10/23

https://indico-tdli.sjtu.edu.cn/event/1696/

Small workshop with sufficient time for discussions

The Era of Anomalies

Kim Siang Khaw



APS Physics

NEWS FEATURE

The Era of Anomalies

May 14, 2020 • *Physics* 13, 79

Particle physicists are faced with a growing list of "anom… results that conflict with the standard model but fail to … sufficient evidence.

For their study of the muon anomaly, the Muon g-2 Collaboratio… magnet halfway across the US in the summer of 2013.

Anomalies in Particle Physics

arXiv:2309.03870

Andreas Crivellin[1,2,*] and Bruce Mellado[3,4,**]

[1]Physik-Institut, Universität Zürich, Win…
[2]Paul Scherrer Institut, CH–5232 Villig…
[*]e-mail: andreas.crivellin@psi.ch
[3]School of Physics and Institute for Co… 2050, South Africa
[4]iThemba LABS, National Research F…
[**]e-mail:bmellado@mail.cern.ch

ABSTRACT

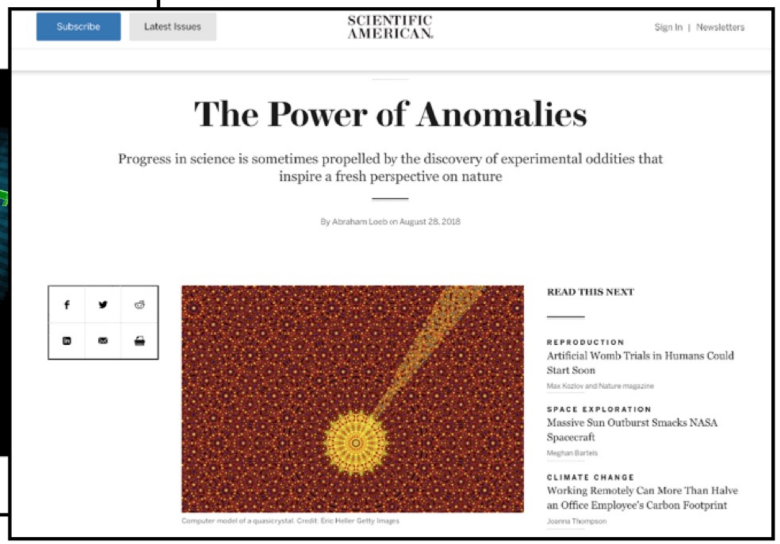
The currently accepted mathematical des… Model of particle physics. Its last missin… at CERN in 2012. However, it is clear th… account for Dark Matter or non-vanishing n… the SM have been intensified since the H… "anomalies", obtained in particle physics e… new resonances at the LHC and indirect l… (approximately the mass of the proton) to th… scale directly accessible at the LHC), the… and theoretical status of the anomalies, w… In particular, new Higgs bosons and lepto… colliders are discussed.

Quanta magazine

Growing Anomalies at the Large Hadron Collider Raise Hopes

Recent measurements of particles called B mesons deviate from predictions. Alone, each oddity looks like a fluke, but their collective drift is more suggestive.

Computer reconstruction of a collision event in the Large Hadron Collider beauty experiment. The collision produces a B meson, which subsequently decays into other particles that strike LHCb's detectors.



SCIENTIFIC AMERICAN

The Power of Anomalies

Progress in science is sometimes propelled by the discovery of experimental oddities that inspire a fresh perspective on nature

By Abraham Loeb on August 28, 2018

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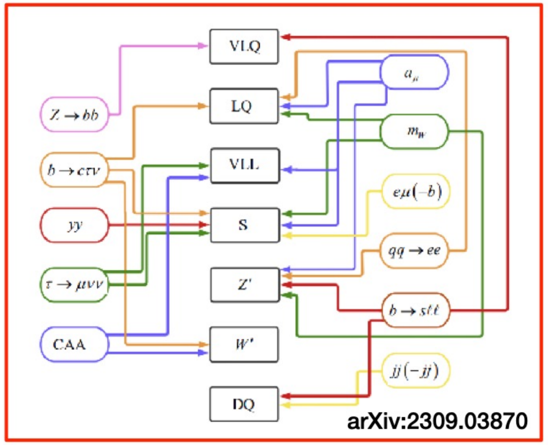
REPRODUCTION
Artificial Womb Trials in Humans Could Start Soon

SPACE EXPLORATION
Massive Sun Outburst Smacks NASA Spacecraft

CLIMATE CHANGE
Working Remotely Can More Than Halve an Office Employee's Carbon Footprint



Field of particle physics is riddled with anomalies.
How can anomalies shed light on the path to observation of BSM?

Definition of Anomaly

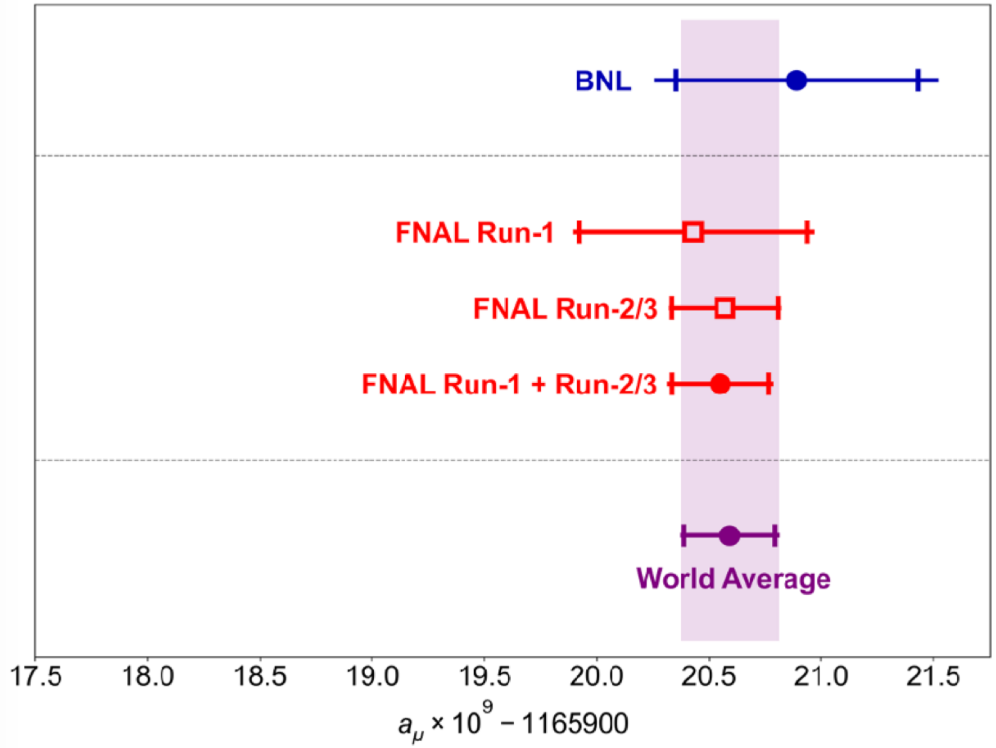
- The global significance of the deviation should be at least three standard deviations (3σ), after the application of trials factors

- The experimental signature should include more than one final state or be observed by more than one independent experiment

- The deviation should be described by a theoretically robust model with a confidence level better than two standard deviations (2σ) and that does not contradict the wealth of existing constraints from particle physics

New World Average

Kim Siang Khaw



- FNAL combination: **203 ppb** uncertainty
- Both FNAL and BNL dominated by statistical error
- Combined world average **dominated by FNAL** values
- Letter can be found at https://arxiv.org/abs/2308.06230 (accepted by PRL)
- A longer paper in PRD will follow soon

a_μ(Exp) = 0.00 116 592 059(22) [190 ppb]

2

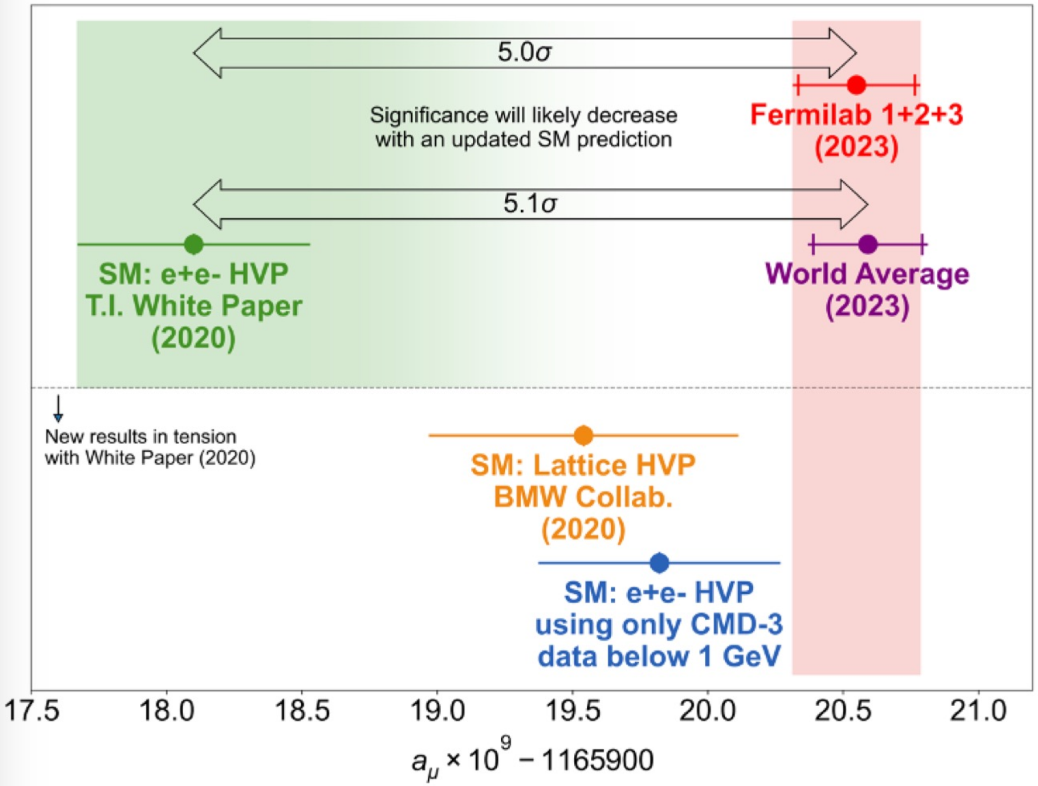
Impressive reduction of systematics

[ppb]	Run-1	Run-2/3	Ratio
Stat.	434	**201**	2.2
Syst.	157	**70**	2.2

Total Run 2/3 uncertainty is **215 ppb**

Experiment / Theory Comparison

Kim Siang Khaw



Disclaimer from A. Keshavarzi's Lattice 2023 talk:

IMPORTANT: THIS PLOT IS VERY ROUGH!

- TI White Paper result has been substituted by CMD-3 only for 0.33 → 1.0 GeV.
- The NLO HVP has not been updated.
- It is purely for demonstration purposes → should not be taken as final!

The CMD-3 point is simply a visual exercise. It is not an updated SM prediction.

- Large discrepancy between experiment and WP (2020)
- Include **BMW** result by swapping HVP from WP with their value
- As expected, BMW falls **in between** WP (2020) and experiment
- Substitute **CMD-3** data for HVP below 1 GeV
- Cherry-picking one experiment but gives a bounding case
- Many **parallel efforts are underway** to resolve the theoretical ambiguity

- Muon g-2 anomaly is explained by TeV scale new physics which can address **naturalness problem** or **dark matter**.

- SUSY is an attractive candidate, but LFV and CPV processes must be suppressed.

- Interpretation by warped extra dimension is (almost) excluded.

- Muon g-2 is a window to explore WIMP dark matter.

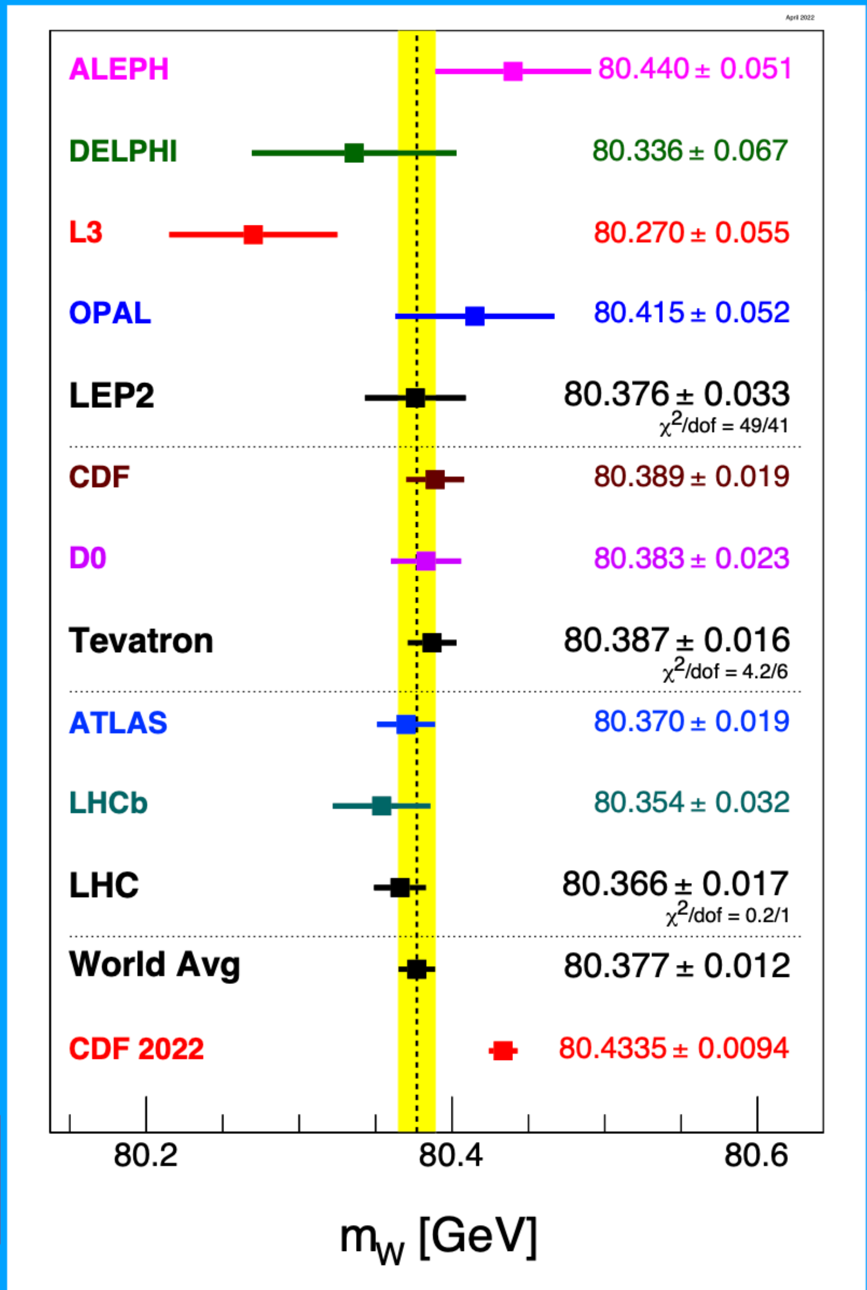
- New physics that addresses muon g-2 anomaly generally predicts muon EDM probed in near future experiments.

The W mass

Chris Hays

Last year's CDF measurement deviated from other measurements and from SM prediction

Measurements used in LHC-TEV MWWG combination



Are we dealing with a Tevatron/LHC discrepancy?

LHC-TeV MW working group was in the process of combining m_W measurements at the time of the CDF measurement

Effort and focus adjusted to include compatibility of full combination and of sub-combinations

Results have now been submitted to EPJC (arXiv:2308.09417)

Yong Du

Δr also depends on m_t, which also has some tension from different experiments

Data	Refs.	Pull (D0/CDF+D0)
$m_t(\text{D0}) = (174.98 \pm 0.76)\,\text{GeV},$	1405.1756(PRL)	—
$m_t(\text{CDF}+\text{D0}) = (174.30 \pm 0.65)\,\text{GeV},$	1608.01881	—
$m_t(\text{ATLAS}) = (172.69 \pm 0.48)\,\text{GeV},$	1810.01772(EPJC)	2.4/2.1
$m_t(\text{CMS}) = (172.44 \pm 0.48)\,\text{GeV},$	1509.04044(PRD)	2.7/2.8
$m_t(\text{CMS}) = (171.77 \pm 0.38)\,\text{GeV},$	CMS PAS TOP-20-008 (2022)	3.7/4.4

Taking this into account, and after performing the global fit, we still cannot explain the anomaly in m_W. Furthermore, resummarilon of color singlets at $\text{N}^3\text{L}^2 + \text{N}^2\text{LO}$ reduces CDF central value by at most 10 MeV, the anomaly still exists.

Isaacson, Fu, Yuan, 2205.02788

Q1: New physics explanation? *Q2: What kind of?*

Are we dealing with a Tevatron/LHC discrepancy in the top mass measurement too?

- I briefly reviewed the m_W anomaly observed by CDF and explained how new physics is needed to accounted for it.

- New physics explanation to the m_W anomaly was discussed in two scenarios: Heavy new physics of universal (S, T, W, Y fit) and non-universal (SMEFT fit) types, and light new physics in specific models (2HDM, leptoquark models, the Zee model etc).

- In each scenarios, the m_W anomaly can be fitted away and be tested at current and/or next generation experiments, and new physics generically is light that can be tested at current and/or next generation experiments.

Light new physics accessible at the e^+e^- collider give plausible explanations

Jin Min Yang

- SUSY confronted with LHC: ok
- SUSY confronted with DM: ok
- Can SUSY explain muon g-2 and W-mass ?

CMSSM, mSUGRA, GMSB, AMSB: need to be extended
MSSM: ok

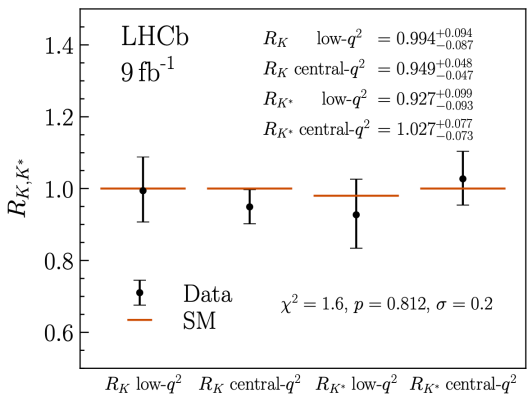
- light electroweakinos
- light sleptons
- light stop

Most hopefully accessible at LHC

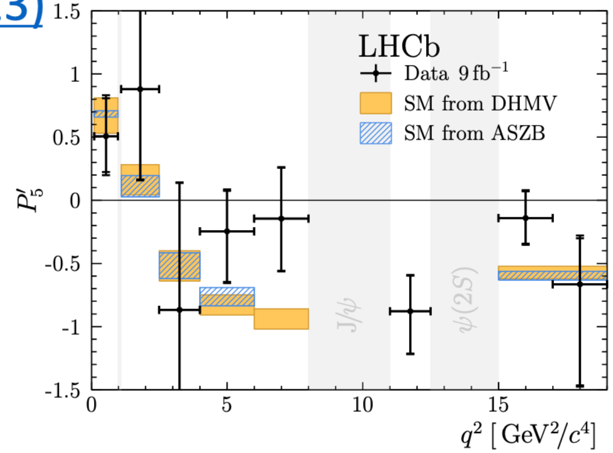
Angular analysis in $b \to s\mu\mu$

Da Yu Tou

- Compared to differential BF, angular analysis observables are cleaner (but not as clean as LFU ratios)
  - Forward-backward asymmetry A_{FB}
  - Longitudinal polarisation F_L
  - P_5' [JHEP 2013, 48 (2013)]

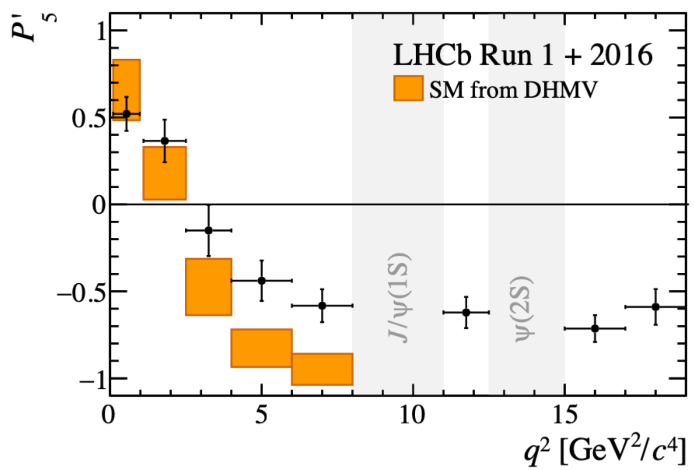


$B^+ \to K^{*+}\mu\mu$



[PRL 126 (2021) 161802]

$B^0 \to K^{*0}\mu\mu$



[PRL 125 (2020) 011802]

Tsinghua University

$b \to s$ll measurement of μ/e ratio is SM-like.

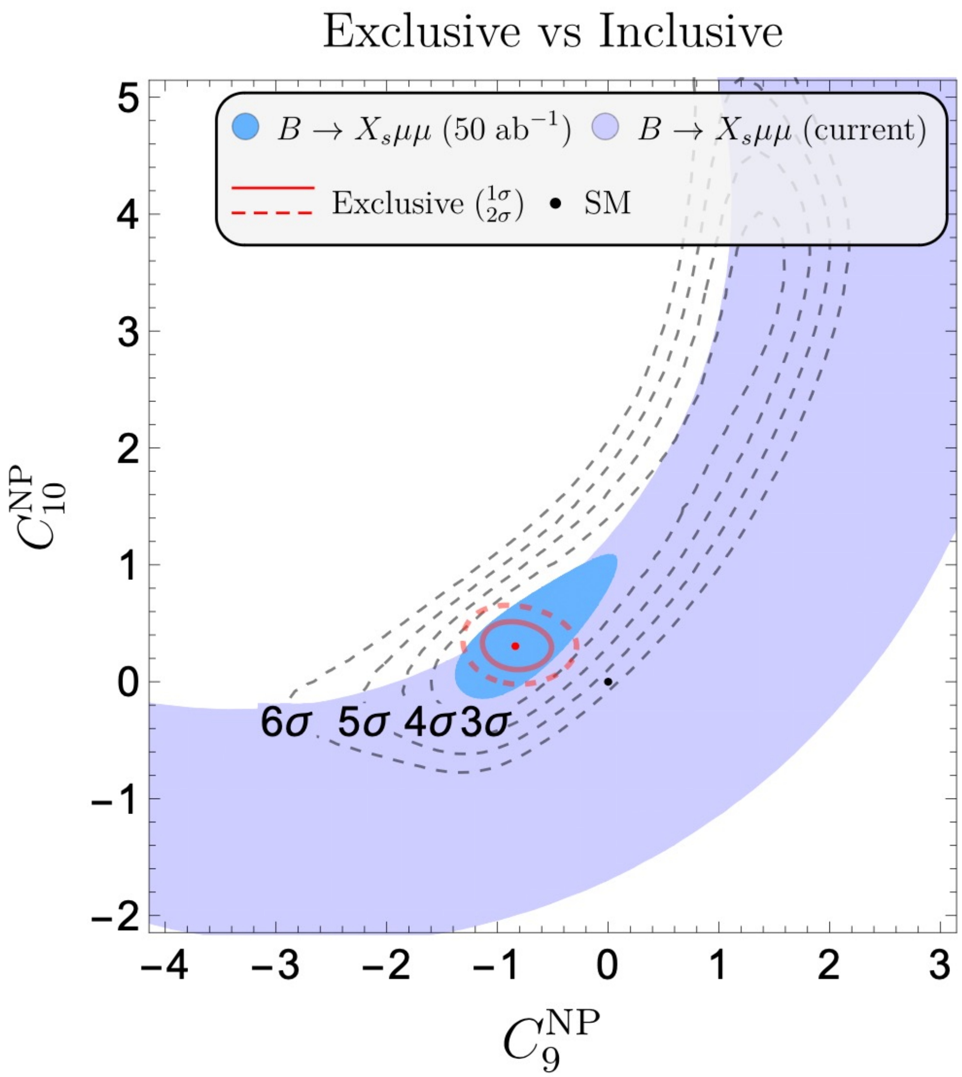
$b \to s\mu\mu$ measurements show consistent pattern of SM deviation.

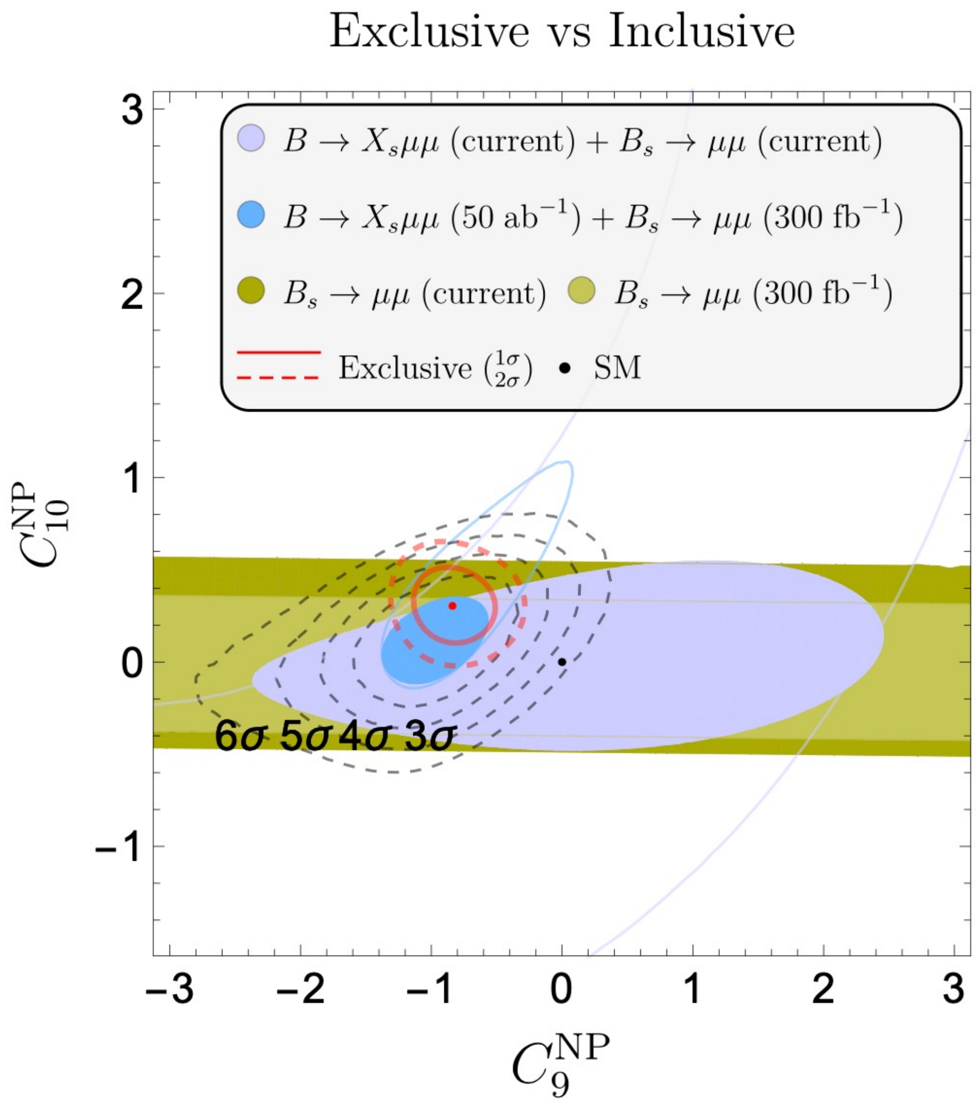
Assuming Belle II measures best fit point of exclusive fit

Huber, Hurth, Jenkins, Lunghi, Qin Qin, Vos, arXiv:2007.04191

Update for post-R_K era

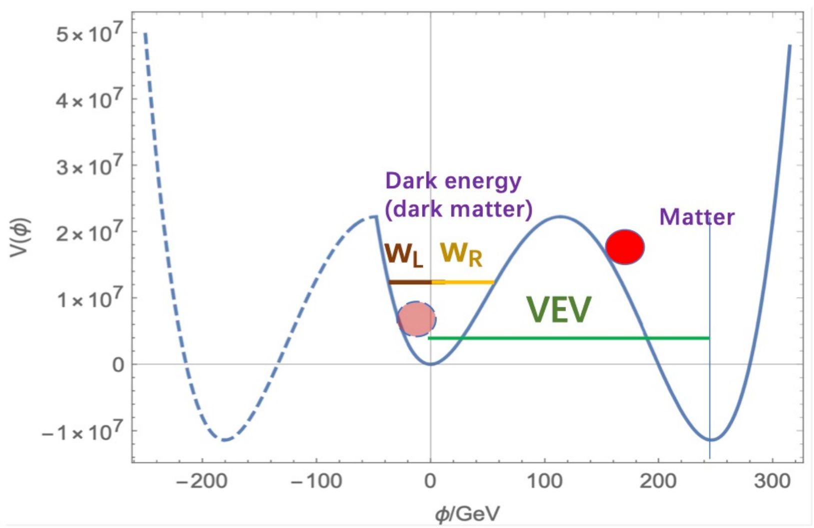
Tobias Hurth





Where are we now and hot to verify the ISB Model

Yaquan Fang



$$m = \alpha V$$

$$\frac{\Delta m}{m} = \frac{\Delta V}{V}$$

Z is the best choice

Particle	α	Δm/GeV deviation	Δm/GeV current uncertainty [9]
W	0.327	8.04×10^{-3}	1.2×10^{-2}
Z	0.371	9.12×10^{-3}	2.1×10^{-3}
H	0.509	1.25×10^{-2}	0.17
top	0.702	1.73×10^{-2}	0.30

- **The masses of the fundamental particles are proportional to VEV (V)**
  - **VEV varies at the different phases of the universe : e.g. VEV increases when the universe expands acceleratively, leading to the variation of the masses for the fundamental patricles.**
- **By measuring the mass for these heavy fundamental particles over time, it is possible to figure it out where we are.**
  - **The top-right table shows one example: the expected deviations of the masses for W,Z,H and top assuming $\frac{\Delta V}{V} \sim 10^{-4}$ and the current precisions from the colliders.**

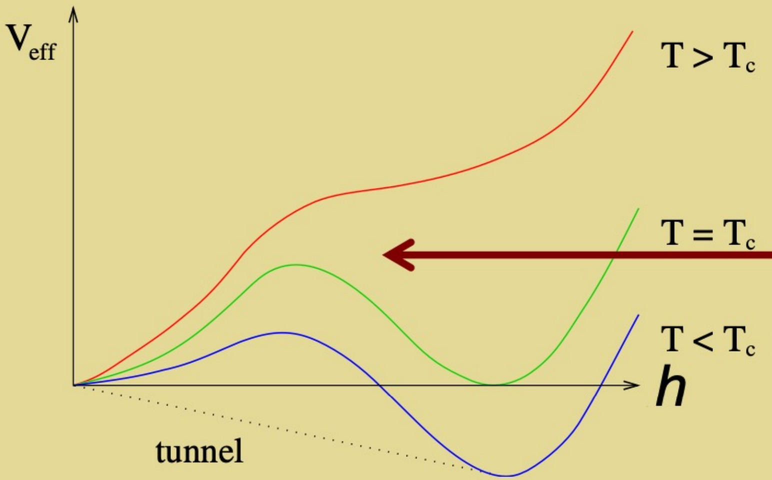
If the deviation of the W mass is true, we may expect the measured Z mass from LHC to be lower than LEP

Signs of New Bosons

MJRM: 1912.07189

Michael Ramsey-Musolf, CEPC2023 Opening Talk

First Order EWPT from BSM Physics

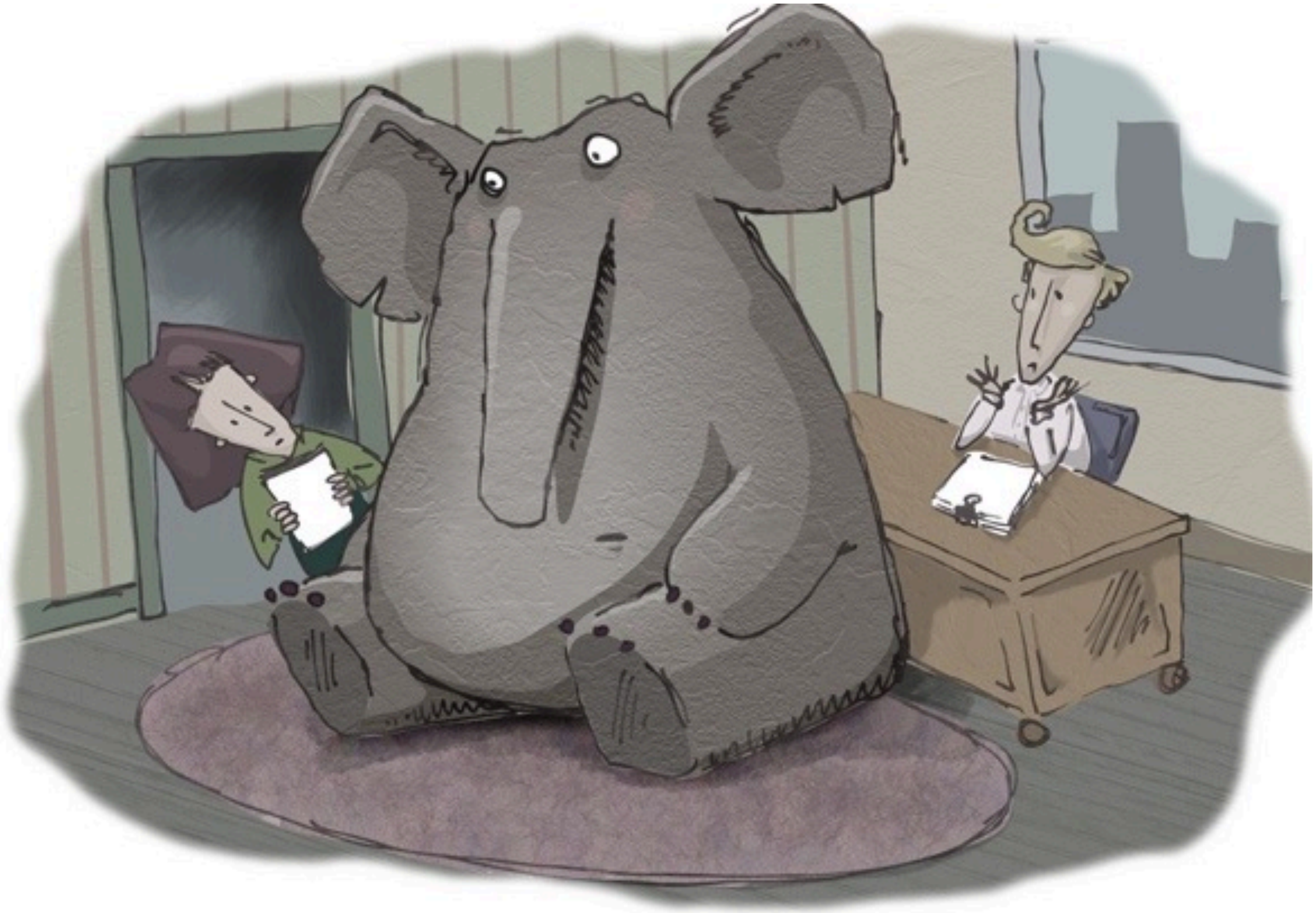


Generate finite-T barrier

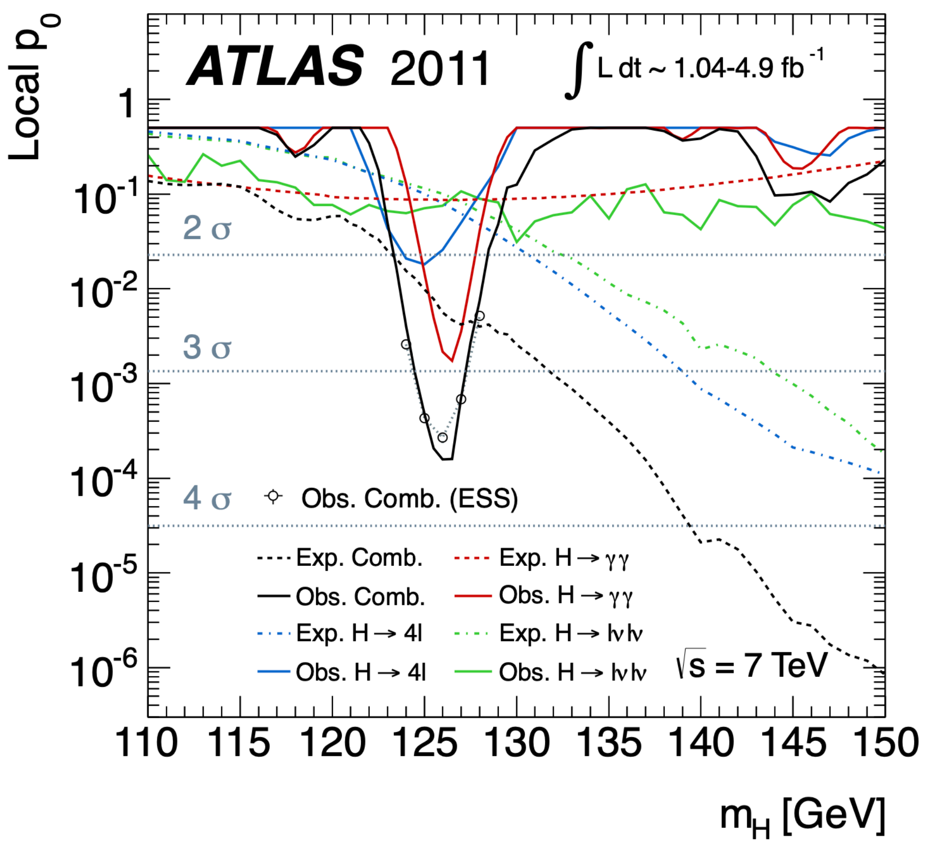
Introduce new scalar ϕ interaction with h via the Higgs Portal

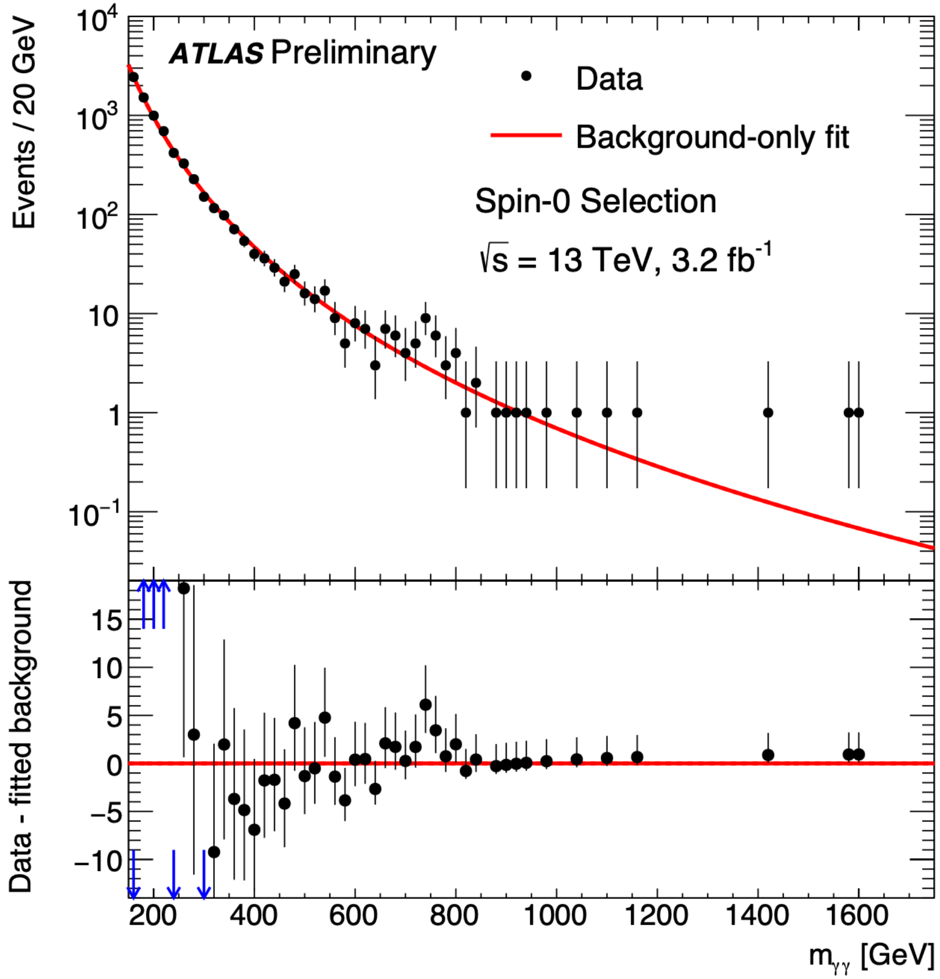
- $M_\phi \lesssim 700$ GeV
- h-ϕ mixing: $|\sin\theta| \gtrsim 0.01$

Let's address the Big Elephant in the room



ATLAS, *Phys.Lett.B* 710 (2012) 49-66





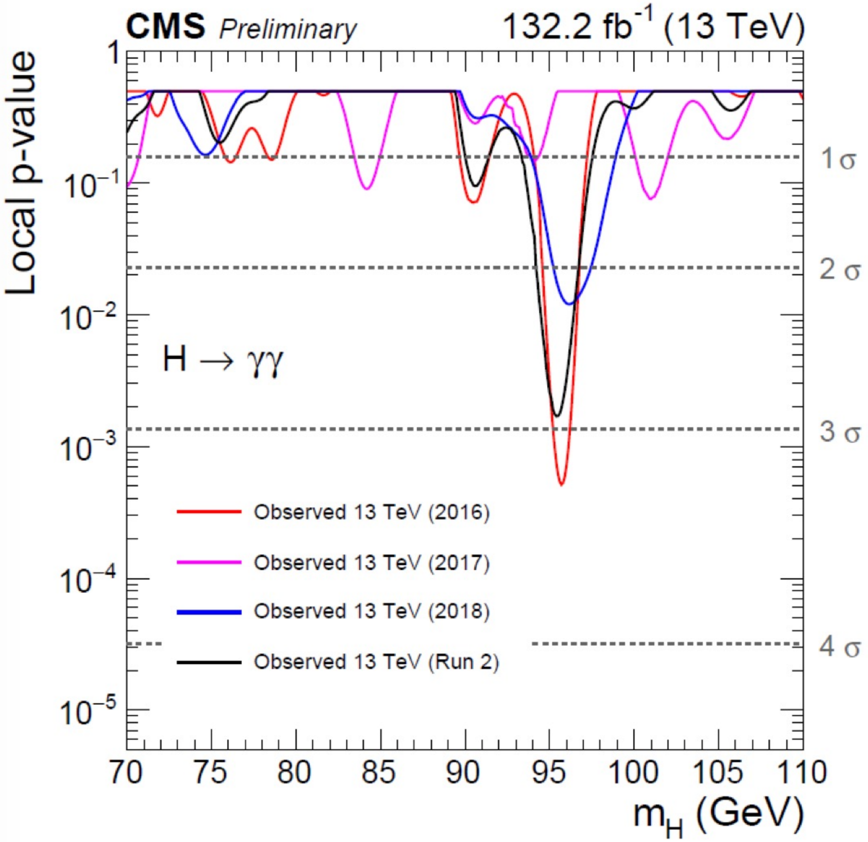
125 GeV	Criterion	750 GeV
YES	**Multiple final states**	**NO**
YES	**Indirect evidence**	**NO**
YES	**Theoretical motivation and explanation**	**?**

The 750 GeV excess had several red flags from inception

Junquan Tao

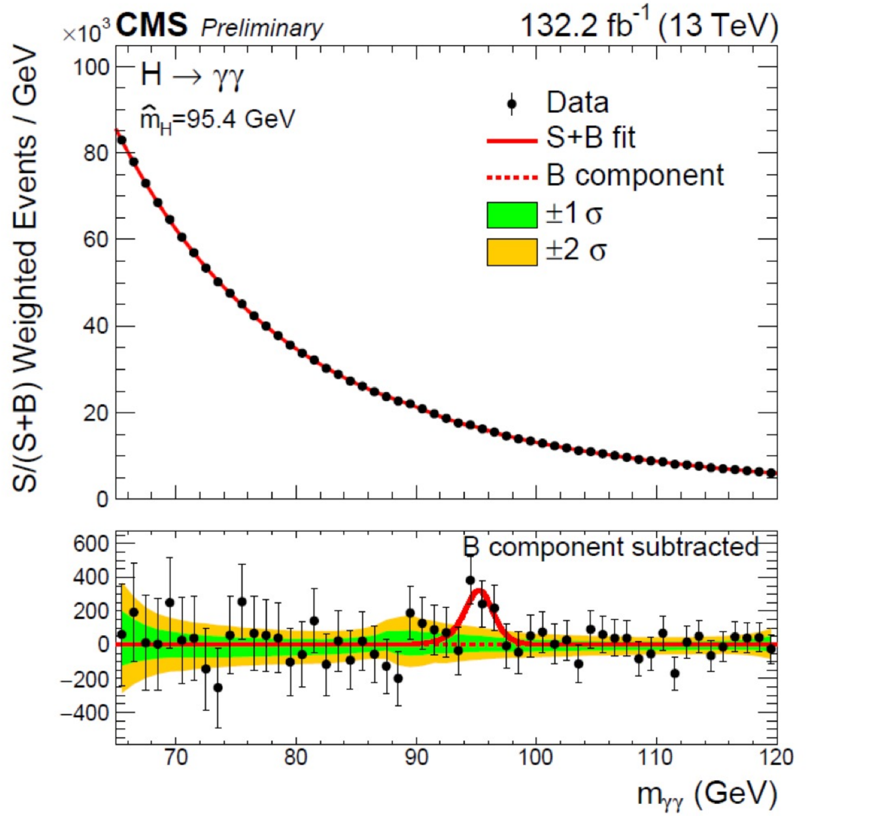
Significances and mass spectrum

- Observed local p-values for 2016, 2017, 2018 and combination



The excess did not grow with luminosity, but remains intriguing

- **S/(S+B)-weighted** $m_{\gamma\gamma}$ distribution with S+B fit for m_H =95.4 GeV



CMS 132/fb @ 13 TeV:

2.9σ local (1.3σ global) @ $m_{\gamma\gamma}$=95.4 GeV

CMS-PAS-HIG-20-002

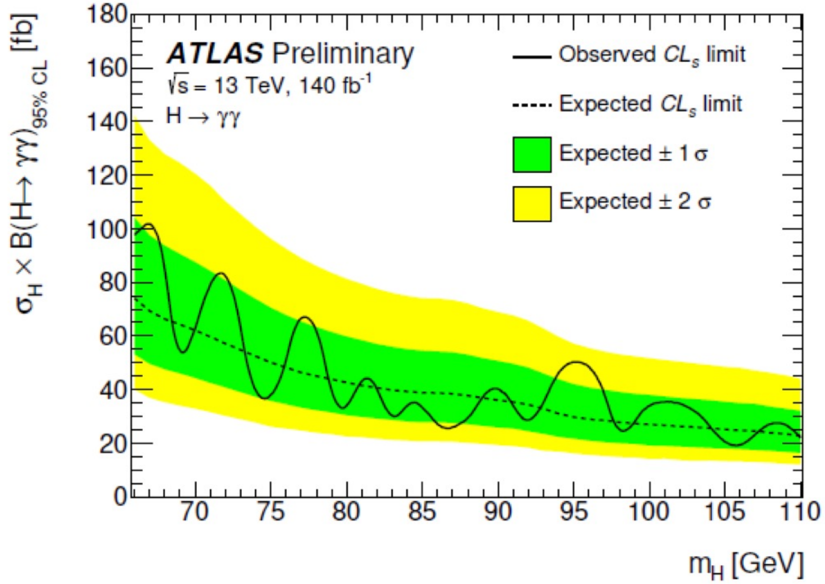
11

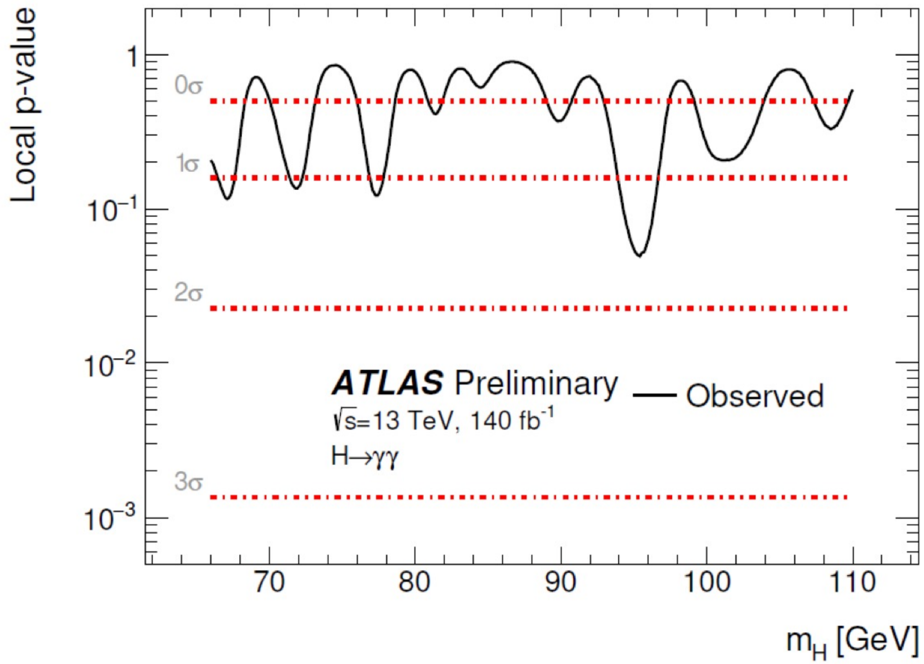
Junquan Tao

ATLAS low-mass $h \to \gamma\gamma$ search results

ATLAS-CONF-2023-035

- The number of signal and background events is measured with an extended **maximum-likelihood fit to the $m_{\gamma\gamma}$ spectra** in the nine categories
- No significant excess is observed
- Upper limit $\sigma_{tot} \times$ BR = [19,102] fb @ 95 % CL





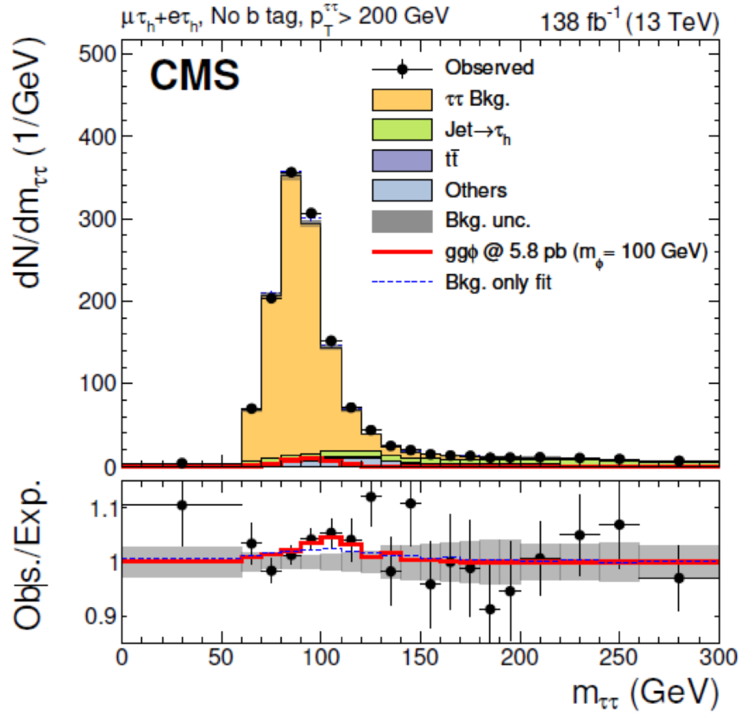
1.7σ @ 95.4 GeV

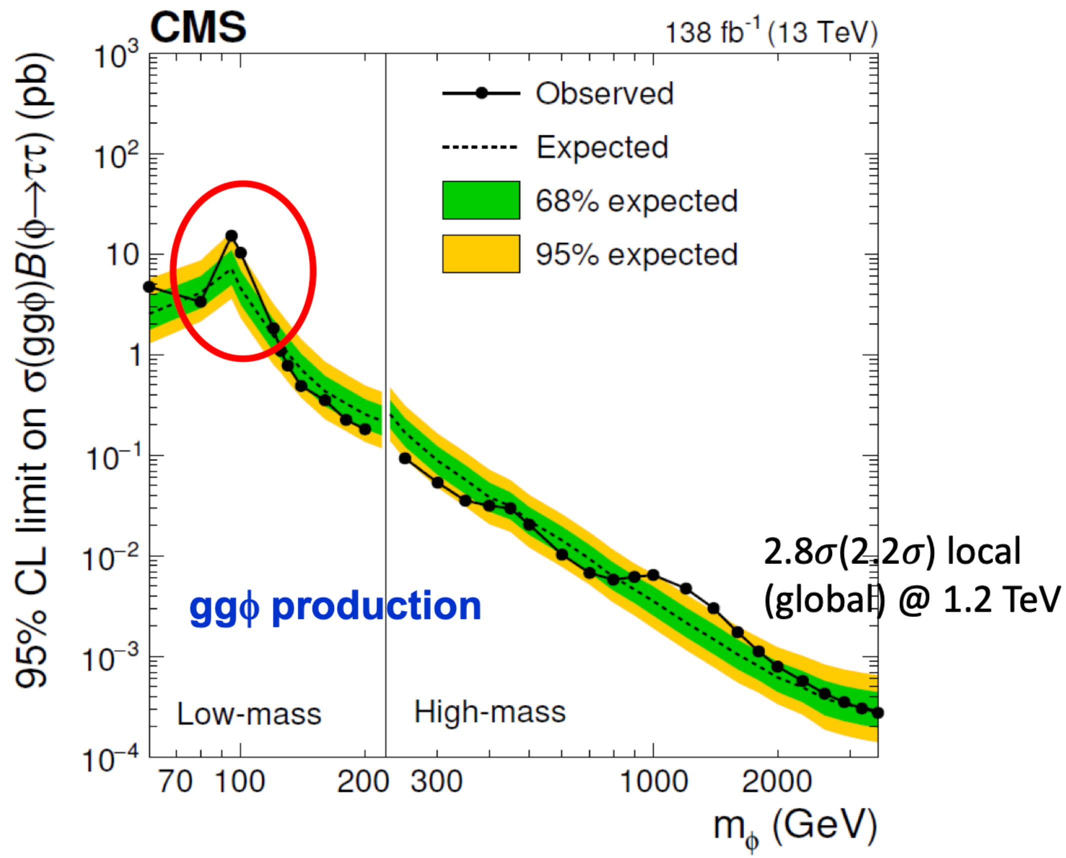
15

$\phi \rightarrow \tau\tau$: results

JHEP07(2023)073

- "Low-mass" (60–250 GeV): fitting on $m_{\tau\tau}$ to extract signal





3.1σ(2.7σ) local (global) @ 100 GeV

$\mu(gg \rightarrow h \rightarrow \tau\tau) = 1.2 \pm 0.5$

2.6σ(2.3σ) local (global) @ 95 GeV

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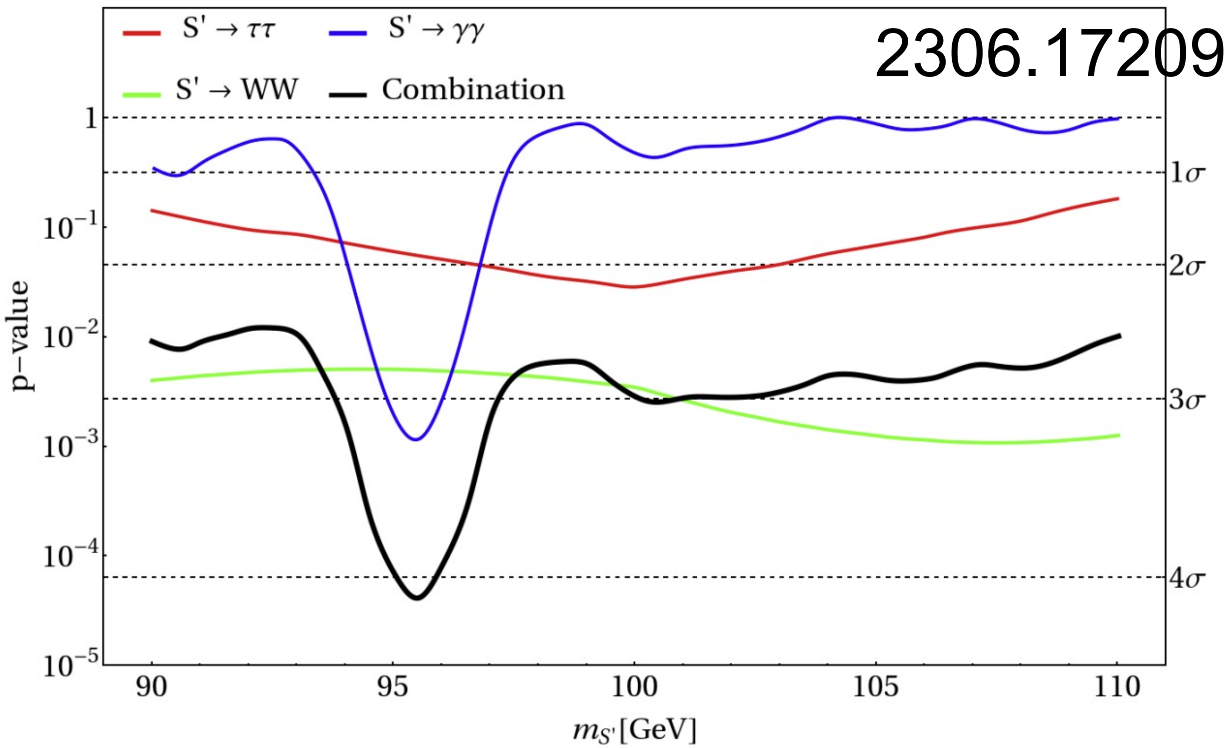
95 Combination

Andreas Crivellin

- Use LEP to reduced the mass range and thus the look-elsewhere effect, fit with 3DoF
- No ATLAS signal in ττ; significance reduced



3.8 global significance

Sven Heinemeyer

Overview I:

[*taken from T. Biekötter '23*]

Models: Summary

Karlsruher Institut für Technologie

Authors	Model	arXiv	Excesses	Comments
Cao, Guo, He et al.	nNMSSM	1612.08522	$bb + \gamma\gamma$	
Fox, Weiner	2HDM + VL	1710.07649	$bb + \gamma\gamma$	
Haisch, Malinauskas	2HDM	1712.06599	$bb + (\gamma\gamma)$	
TB, Heinemeyer, Muñoz	$\mu\nu$SSM	1712.07475	$bb + \gamma\gamma$	EW seesaw
Liu, Liu, Wagner, Wang	$U(1)_{L_\mu - L_\tau}$	1805.01476	$bb + \gamma\gamma$	B-anomalies
Domingo, Heinemeyer, Paßehr, Weiglein	NMSSM	1807.06322	$bb + \gamma\gamma$	
Hollik, Liebler, Moortgat-Pick et al.	μNMSSM	1809.07371	$bb + \gamma\gamma$	Inflation
TB, Chakraborti, Heinemeyer	N2HDM	1903.11661	$bb + \gamma\gamma$	
Cline, Toma	pNG + squarks	1906.02175	$bb + \gamma\gamma$	DM
Choi, Hui Im, Sik Jeong et al.	gNMSSM	1906.03389	$bb + \gamma\gamma$	
Cao, Jia, Yue et al.	nNMSSM	1908.07206	$bb + \gamma\gamma$	Type-I seesaw
Aguilar-Saavedra, Joaquim	SM + $U(1)_{Y'}$	2002.07697	$bb + \gamma\gamma$	
TB, Olea-Romacho	S2HDM	2108.10864	$bb + \gamma\gamma$	DM, GC excess
TB, Grohsjean, Heinemeyer et al.	NMSSM	2109.01128	$\gamma\gamma$	400 GeV excess
Heinemeyer, Lika, Moortgat-Pick et al.	2HDM+s	2112.11958	$bb + \gamma\gamma$	
TB, Heinemeyer, Weiglein	N2HDM	2203.13180	$bb + (\tau\tau) + \gamma\gamma$	
TB, Heinemeyer, Weiglein	N2HDM	2204.05975	$bb + (\tau\tau) + \gamma\gamma$	CDF M_W
Benbrik, Boukidi, Moretti et al.	A2HDM-III	2204.07470	$bb + \gamma\gamma$	LFV

Green: 2HDM(+X), blue: Susy, red: Extra charged fields

Authors	Model	arXiv	Excesses	Comments
TB, Heinemeyer, Weiglein	S2HDM	2303.12018	$bb + (\tau\tau) + \gamma\gamma$	DM
Azevedo, TB, Ferreira	C2HDM	2305.19716	$bb + \tau\tau + \gamma\gamma$	
Bonilla, Carcamo, Kovalenko et al.	Left-Right model	2305.11967	$\gamma\gamma$	DM
TB, Heinemeyer, Weiglein	S2HDM	2306.03889	$bb + (\tau\tau) + \gamma\gamma$	ATLAS-$\gamma\gamma$
Escribano, Martín Lozano, Vicente	Scotogenic	2306.03735	$bb + \gamma\gamma$	DM, ν masses
Belyaev, Benbrik, Boukidi et al.	A2HDM	2306.09029	$bb + (\tau\tau) + \gamma\gamma$	
Ashanuman, Banik, Coloretti et al.	$Y = 0$ triplet	2306.15722	$\gamma\gamma$	CDF M_W
Aguilar-Saavedra, Camara, Joaquim et al.	UN2HDM	2307.03768	$(\tau\tau)$, $\gamma\gamma$	

Multi-lepton Anomalies →150 GeV Boson

- Deviations from the SM predictions in LHC processes involving two or more leptons, with and

Final state	Characteristics	SM backgrounds	Significance
$\ell^+\ell^-$+(b-jets)[62,65,66]	$m_{\ell\ell} < 100\,\mathrm{GeV}$, $(1b, 2b)$	$t\bar{t}, Wt$	$> 5\sigma$
$\ell^+\ell^-$+(no jet)[61,67]	$m_{\ell\ell} < 100\,\mathrm{GeV}$	W^+W^-	$\approx 3\sigma$
$\ell^\pm\ell^\pm, 3\ell$ + (b-jets)[64,68,69]	Moderate H_T	$t\bar{t}W^\pm, t\bar{t}t\bar{t}$	$> 3\sigma$
$\ell^\pm\ell^\pm, 3\ell$, (no b-jet)[63,70,71]	In association with h	$W^\pm h(125), WWW$	$\gtrapprox 4\sigma$
$Z(\to \ell\ell)\ell$, (no b-jet)[62,72]	$p_T^Z < 100\,\mathrm{GeV}$	$ZW^\pm$	$> 3\sigma$

A.C., B. Mellado, arXiv:2309.03870

Andreas Crivellin

- 1711.07874 found m_S=150±5GeV

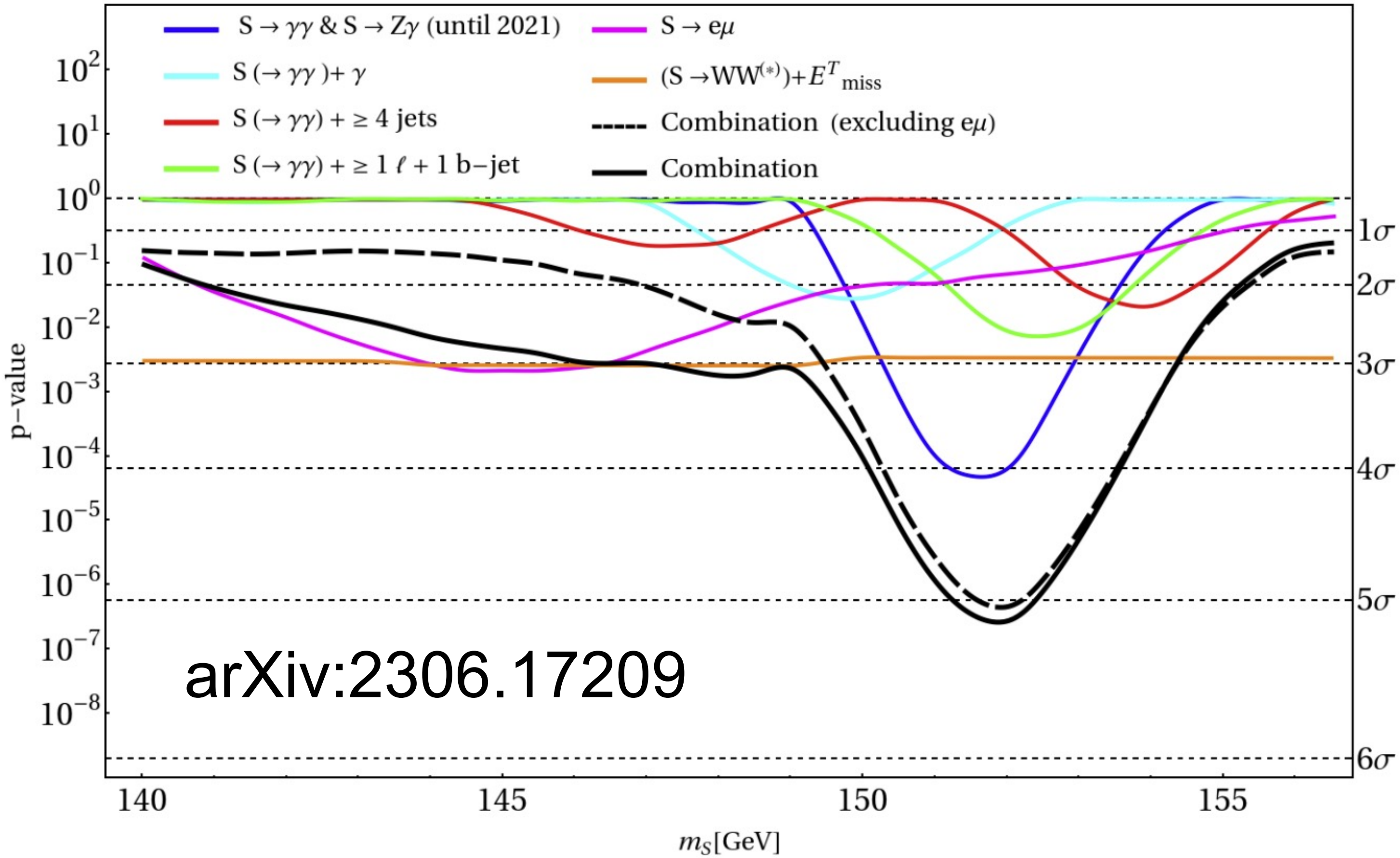
Buddenbrock et al. arXiv:1901.05300
O. Fischer et al. arXiv: 2109.06065

Statistically significant, motivate new EW scale scalars

152 GeV Combination

Andreas Crivellin

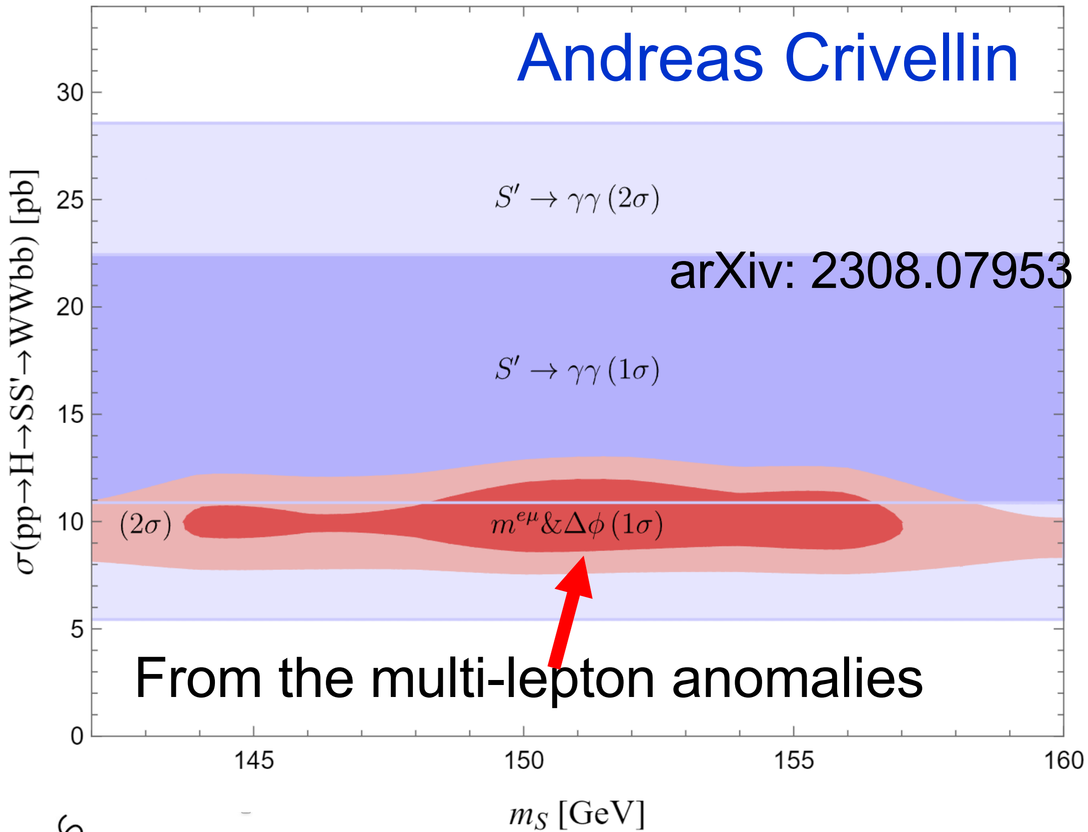
- Run 1 indications for a new scalar (1711.07874) motivate the combination but are NOT included

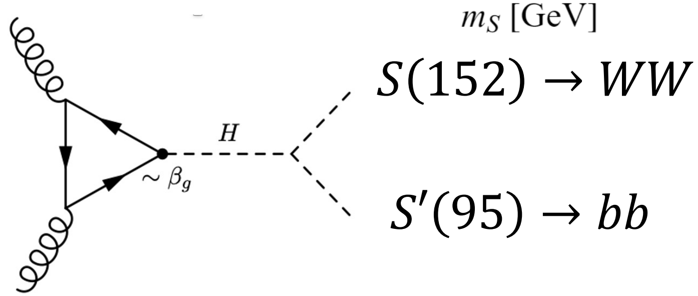


4.9 global significance

Singlet S′(95)+Triplet S(152) Model

- S’(95): Singlet decays dominantly to bb
- S(152):Triplet with Y=0, motivated by the W mass decays dominantly to WW
- Agreement with 95→γγ signal strength



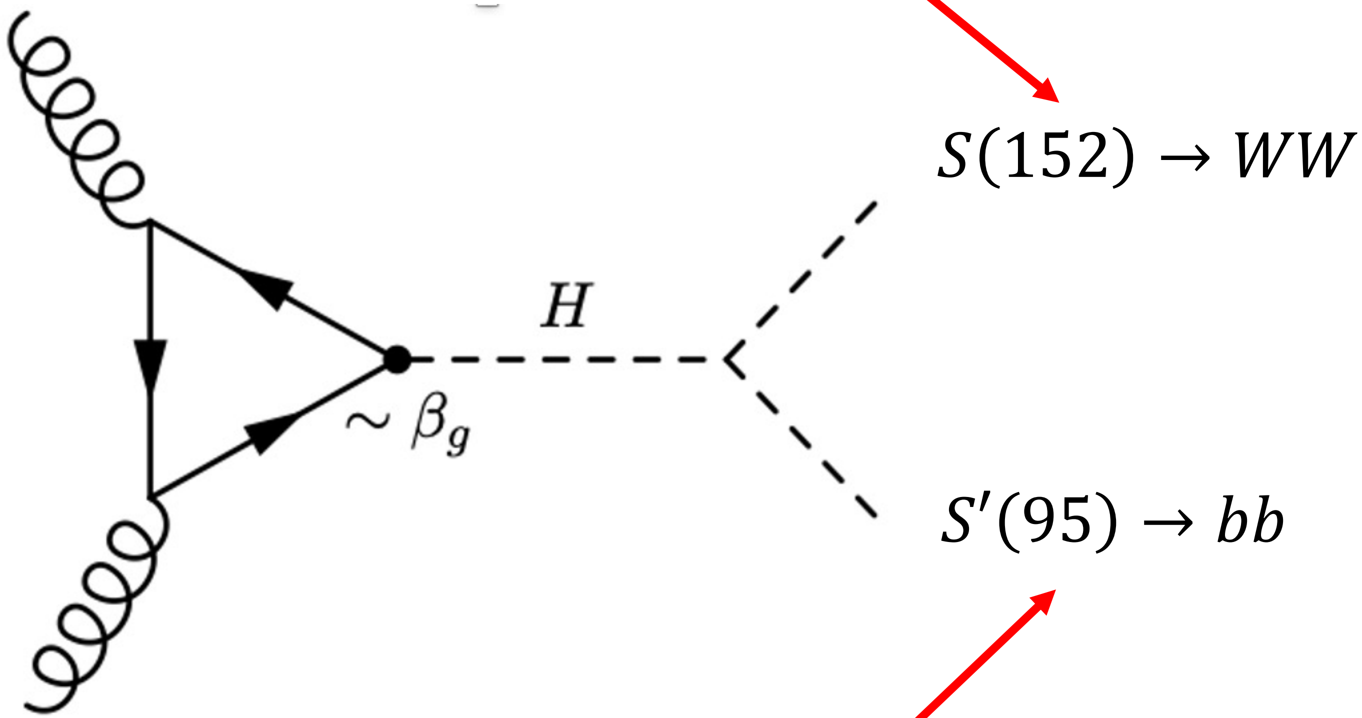


Independent, but consistent with 152GeV excess

Potential contributor to multi-lepton anomalies at the LHC

Also could provide the indirect support for the 95 GeV candidate

Source of leptons



Source of b-jets

A plea for a 650 GeV Boson

Francois Richard

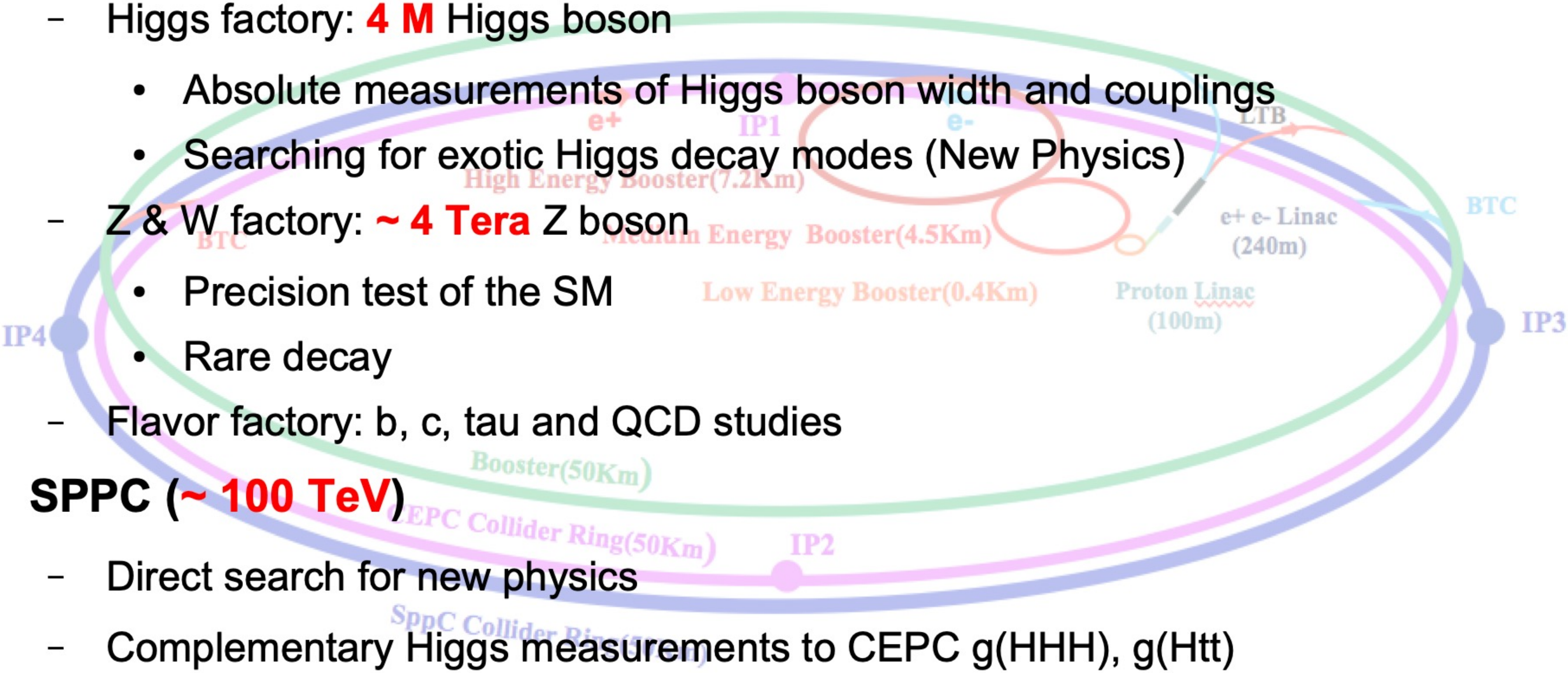
- With RUN2 data there has been growing evidence for a wide resonance with M=650 GeV and Γtot=100 GeV
- Historically this work started in 2018 *1806.04529* with the mode ZZ, confirmed by *2103.01918*, then came WW *2104.04762* and h(95)h(125) **HIG-21-011**
- Note in passing the connection between h(95) and H(650)
- Putting them together, one reaches 6 s.d. global (Fisher method)
- Question: how to interpret this resonance in the context of existing phenomenology ?
- Caveat : we cannot exclude that it is a tensor (G_{KK} of the RS type etc…)

Impact on Future e^+e^- Colliders

Key parameters of the CEPC-SPPC

Manqi Ruan

- **Tunnel ~ 100 km**
- **CEPC (90 – 240 GeV)**
  - Higgs factory: **4 M** Higgs boson
    - Absolute measurements of Higgs boson width and couplings
    - Searching for exotic Higgs decay modes (New Physics)
  - Z & W factory: **~ 4 Tera** Z boson
    - Precision test of the SM
    - Rare decay
  - Flavor factory: b, c, tau and QCD studies
- **SPPC (~ 100 TeV)**
  - Direct search for new physics
  - Complementary Higgs measurements to CEPC g(HHH), g(Htt)
  - ...
- **Heavy ion, e-p collision...**



Complementary

Low mass Higgs bosons...

Manqi Ruan

The Observation of a 95 GeV Scalar at future e^+e^- Colliders

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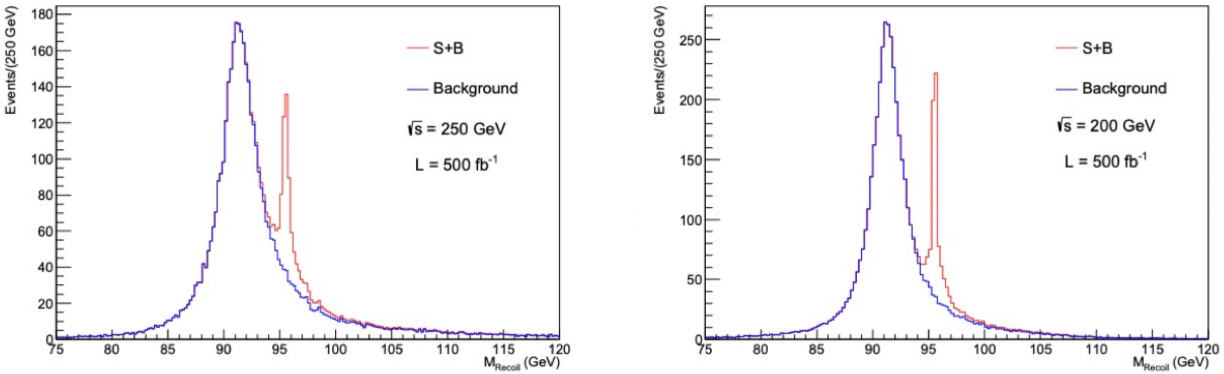


Figure 1. Recoil mass distribution for simulated $e^+e^- \to HZ \to H\mu^+\mu^-$ events with $m_S = 95, 5$ GeV and all relevant background events after a pre-selection described in this section for (a) $\sqrt{S} = 250$ GeV and (b) $\sqrt{S} = 200$ GeV both at integrated luminosity $\mathscr{L} = 500$ fb^{-1}; measured with the CLIC_ILD detector concept. This is achieved by considering the BSM signal to be 10% SM Higgs-like.

- *Assume signal Xsec ~ 20 fb*
- *CEPC Higgs operation: ~ 6 fb^{-1}/day ~ 2 ab^{-1}/year*
- *Turn-key discovery*

...Preliminary...

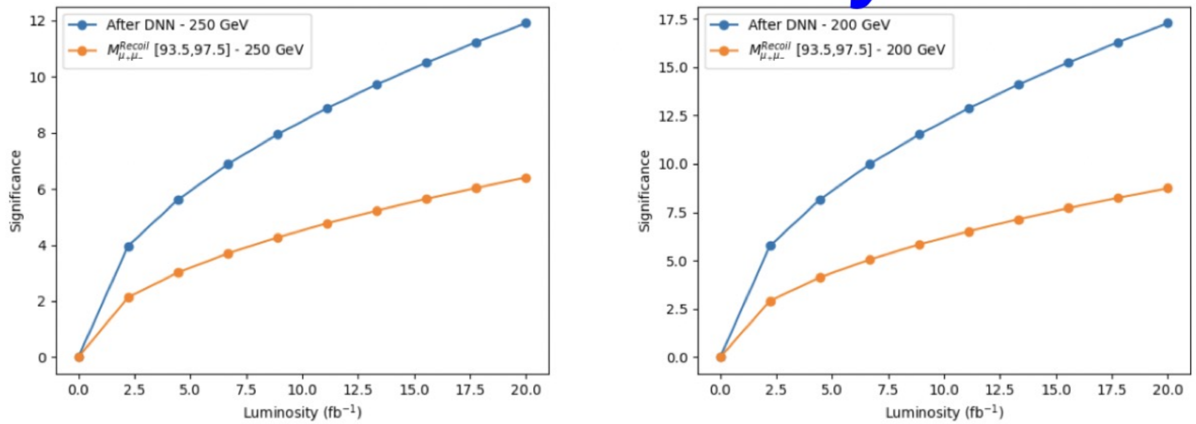


Figure 5. The signal significance as a function of Luminosity ($\mathscr{L}$) for (left) $\sqrt{s} = 250$ GeV before (Orange) and after DNN (Blue), (right) $\sqrt{s} = 200$ GeV before (Orange) and after DNN (Blue) respectively.

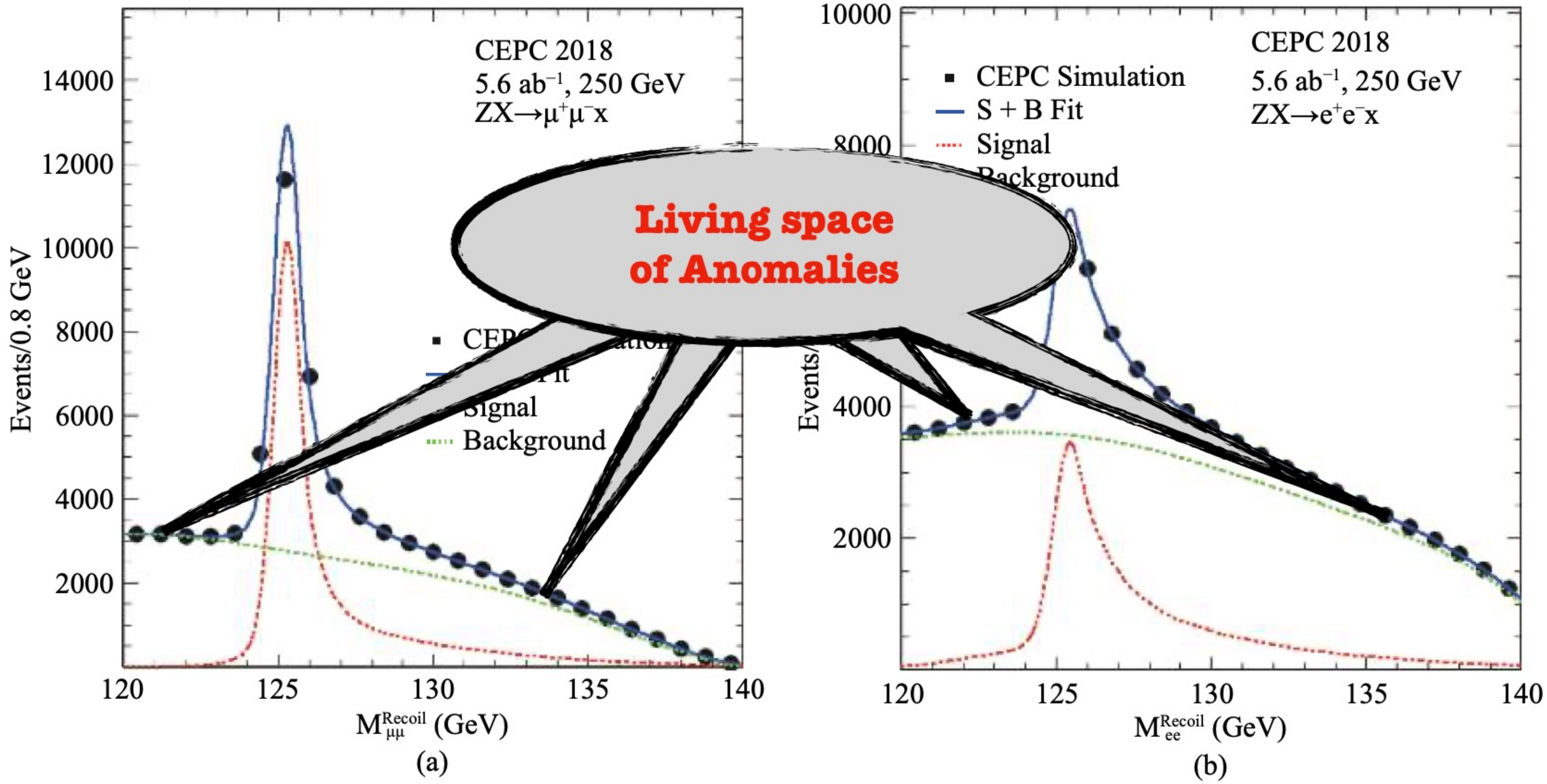
21/9/2023

Conclusive observation of a 95 GeV state in e^+e^- collisions

- 240GeV, ~5.6ab^{-1} integrated luminosity, 10^6 Higgs bosons.

Hao Zhang

- Precisely measurements of the SM-like Higgs boson:



F. An, et al, Chin. Phys. C43 (2019) 043002;

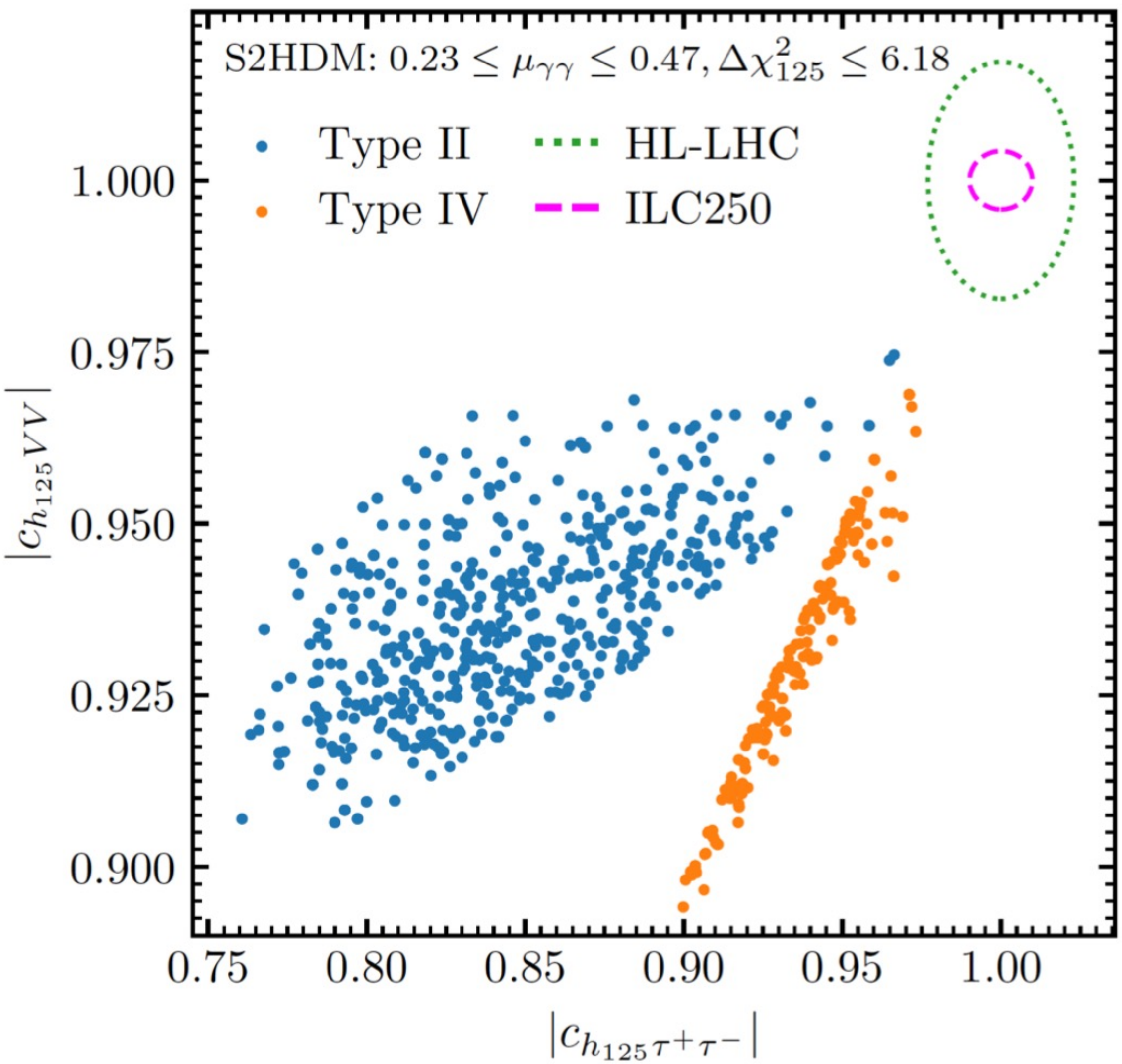
h_{125} coupling measurements at the HL-LHC/ILC

[*T. Biekötter, S.H., G. Weiglein '23*]

Sven Heinemeyer

Emergence of new physics at the EW naturally impacts h(125) couplings.

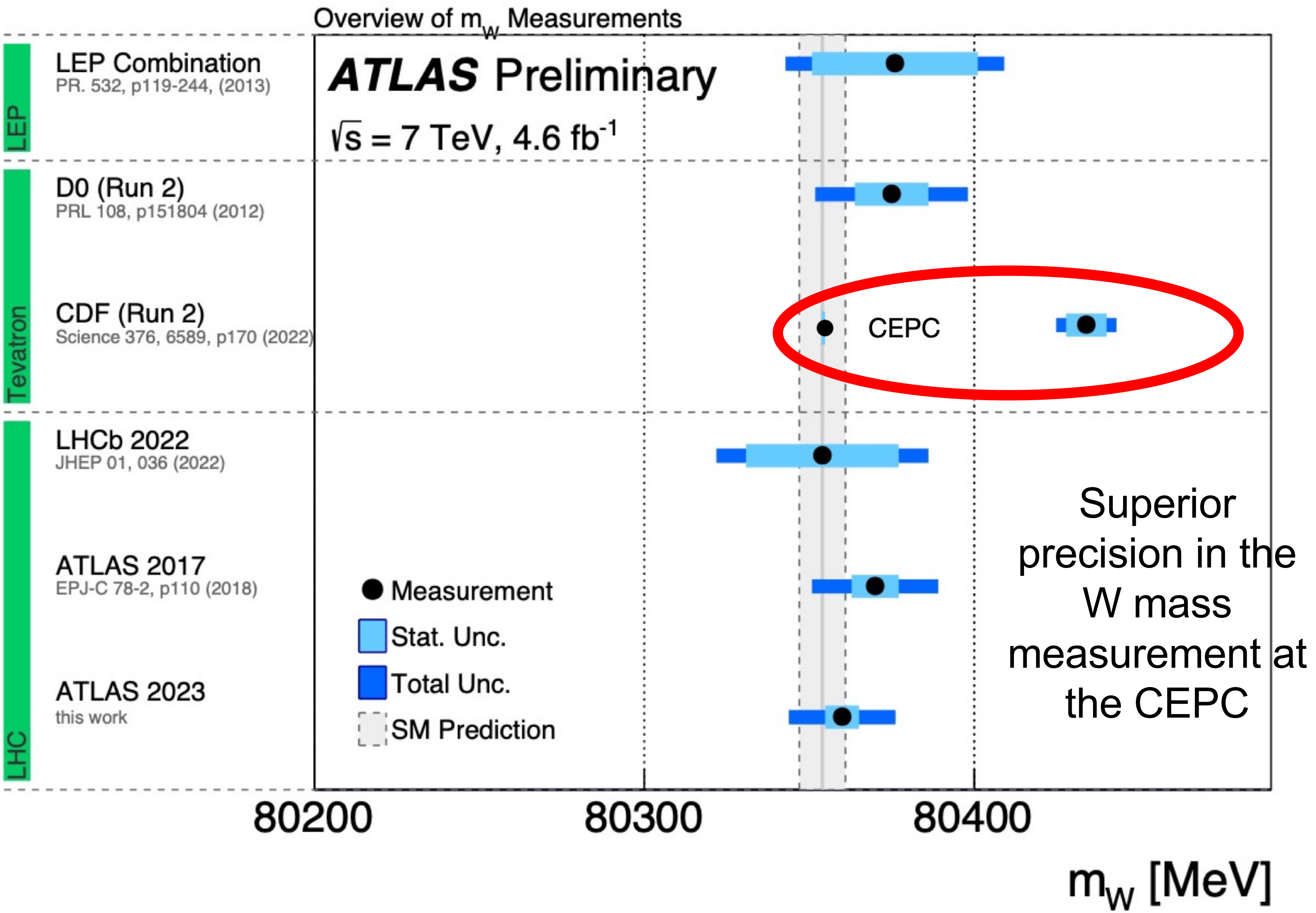
These will be measured with high accuracy at Higgs factories



$\Rightarrow$ both types show some deviation from SM

- 160-180GeV, ~2.6ab^{-1} integrated luminosity.

Hao Zhang



e^+e^- accelerator is central to resolving where the W mass stands

Muon g-2

h(125) coupling

Z Pole

152 GeV

95 GeV

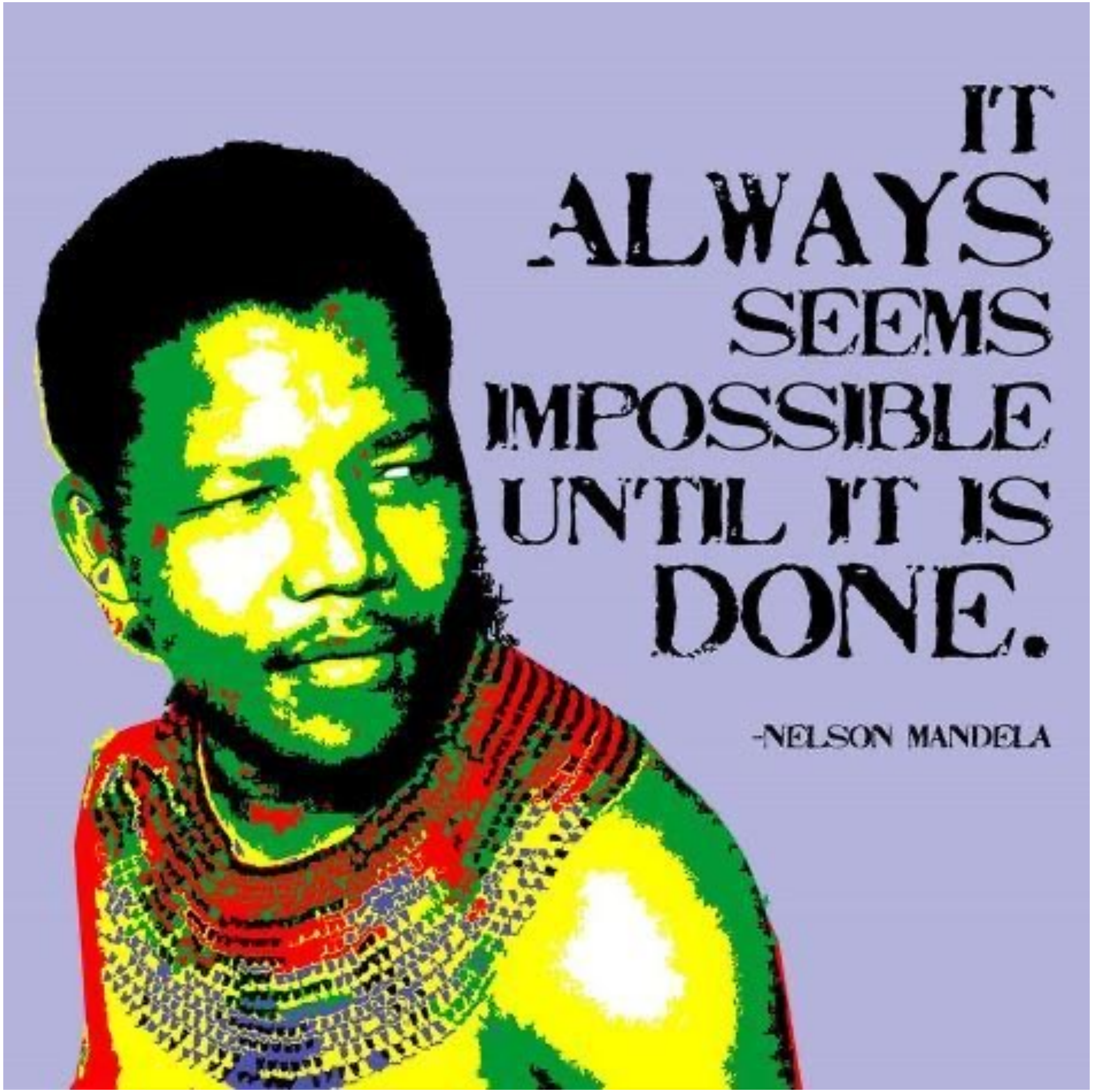
W Wass

Top Mass

The e^+e^- Collider

Discovery machine through precision and direct observation at the EW Scale

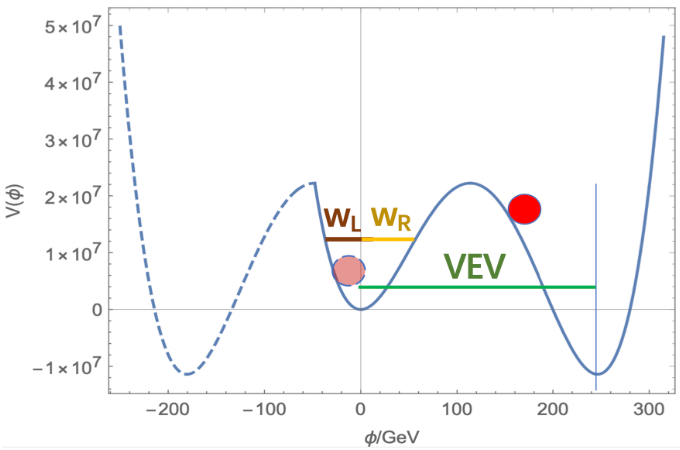
Anomalies in Particle Physics are indicative of unique discovery opportunities at the EW scale for future e^+e^- accelerators


IT ALWAYS SEEMS IMPOSSIBLE UNTIL IT IS DONE.
-NELSON MANDELA

Additional Slides

Two Parameters for ISB Model and the Relation with the Dark Matter and Dark Energy

Yaquan Fang



Input of current ratios:
Dark matter : 27%
Dark Energy : 68%
Matter : 5%

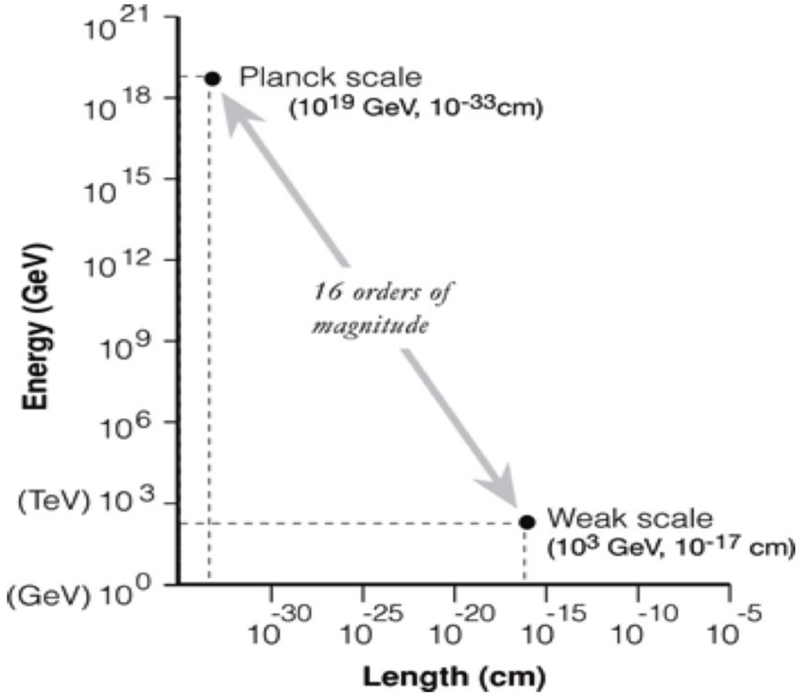
Dark matter vs Dark energy : $\frac{f_d \cdot (W_R - W_L)}{f_d \cdot \frac{1}{2}(W_R + W_L)} \sim \frac{M_{dark\,matter}}{M_{dark\,energy}}$

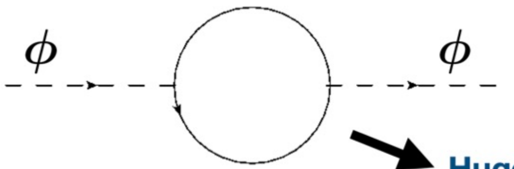
Dark matter vs matter : $\frac{f_d \cdot (W_R - W_L)}{f_m \cdot VEV} \sim \frac{M_{dark\,matter}}{M_{matter}}$

- ✓ $W_R = 1.5\, W_L$
- ✓ $\frac{W_L}{VEV} \sim 10.8 \frac{f_m}{f_d}$
- ✓ $W_L < VEV$ *for the expanded universe*:
  $\frac{f_d}{f_m} > 10.8$
- ✓ If $W_L \sim O(1)\ MeV$, $\frac{f_d}{f_m} \sim O(10^6)$
  - ✓ The ratio is very high

We are excited about **muon g-2 anomaly** because …

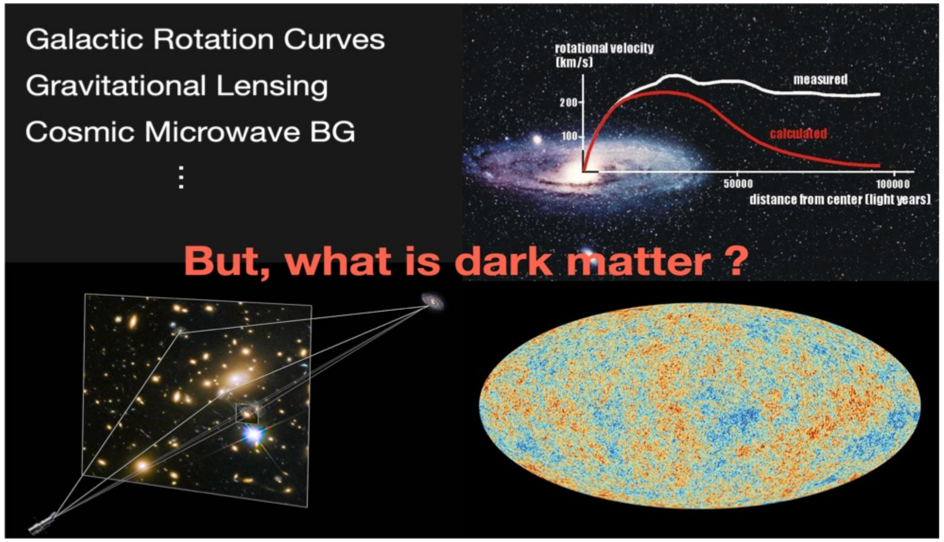
Naturalness problem



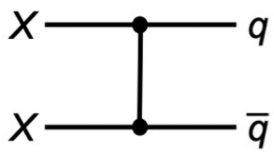


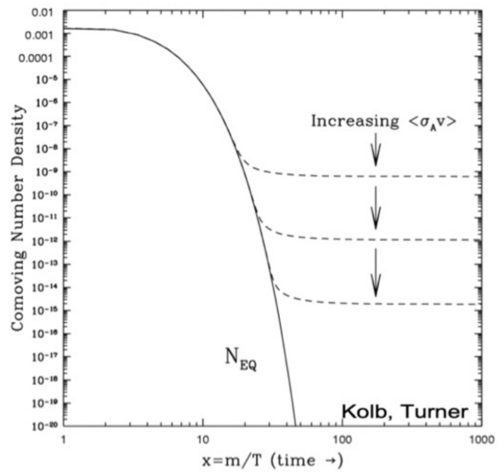
Huge quantum correction

Dark matter



WIMP miracle





Anomaly detection with Machine Learning
Analysis strategy

Rui Zhang

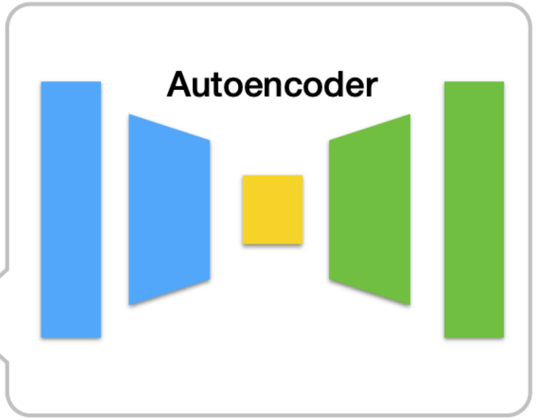
Trigger (one lepton) and pre-selection ($p_T^l > 60$ GeV, $p_T^{\text{jet}} > 30$ GeV)

Rapidity-mass matrix

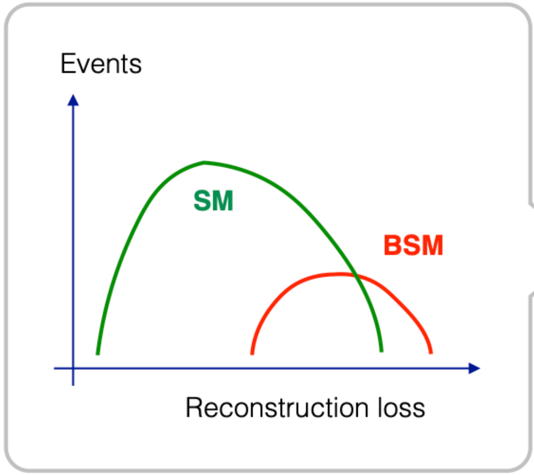
$$\begin{pmatrix} e_T^{miss} & m_T(j_1) & m_T(j_2) & \ldots m_T(j_N) & m_T(\mu_1) & \ldots m_T(\mu_N) \\ h_L(j_1) & e_T(j_1) & m(j_1,j_2) & \ldots m(j_1,j_N) & m(j_1,\mu_1) & ..m(j_1,\mu_N) \\ h_L(j_2) & h(j_1,j_2) & \delta e_T(j_2) & \ldots m(j_2,j_N) & m(j_2,\mu_1) & ..m(j_2,\mu_N) \\ \ldots & \ldots & \ldots & \ldots, & \ldots & \ldots \\ h_L(j_N) & h(j_1,j_N) & \ldots & \ldots \delta e_T(j_N) & m(j_N,\mu_1) & ..m(j_N,\mu_N) \\ h_L(\mu_1) & h(\mu_1,j_1) & h(\mu_1,j_2) & \ldots h(\mu_1,j_N) & e_T(\mu_1) & m(\mu_1,\mu_N) \\ h_L(\mu_2) & h(\mu_2,j_1) & h(\mu_1,j_2) & \ldots h(\mu_2,j_N) & h(\mu_1,\mu_2) & m(\mu_2,\mu_N) \\ \ldots & \ldots & \ldots & \ldots & \ldots & \\ h_L(\mu_N) & h(\mu_N,j_1) & h(\mu_N,j_2) & \ldots h(\mu_N,j_N) & h(\mu_N,\mu_1) & \delta e_T(\mu_N) \end{pmatrix}$$

Reconstruct Rapidity Mass Matrix for each event

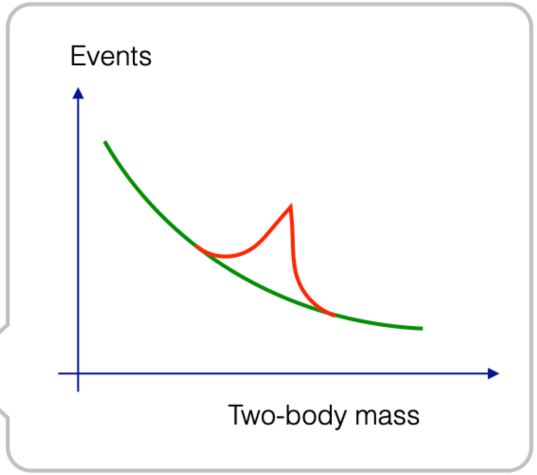
Train autoencoder using 1% ATLAS Run2 data



Define signal region using reconstruction loss from autoencoder

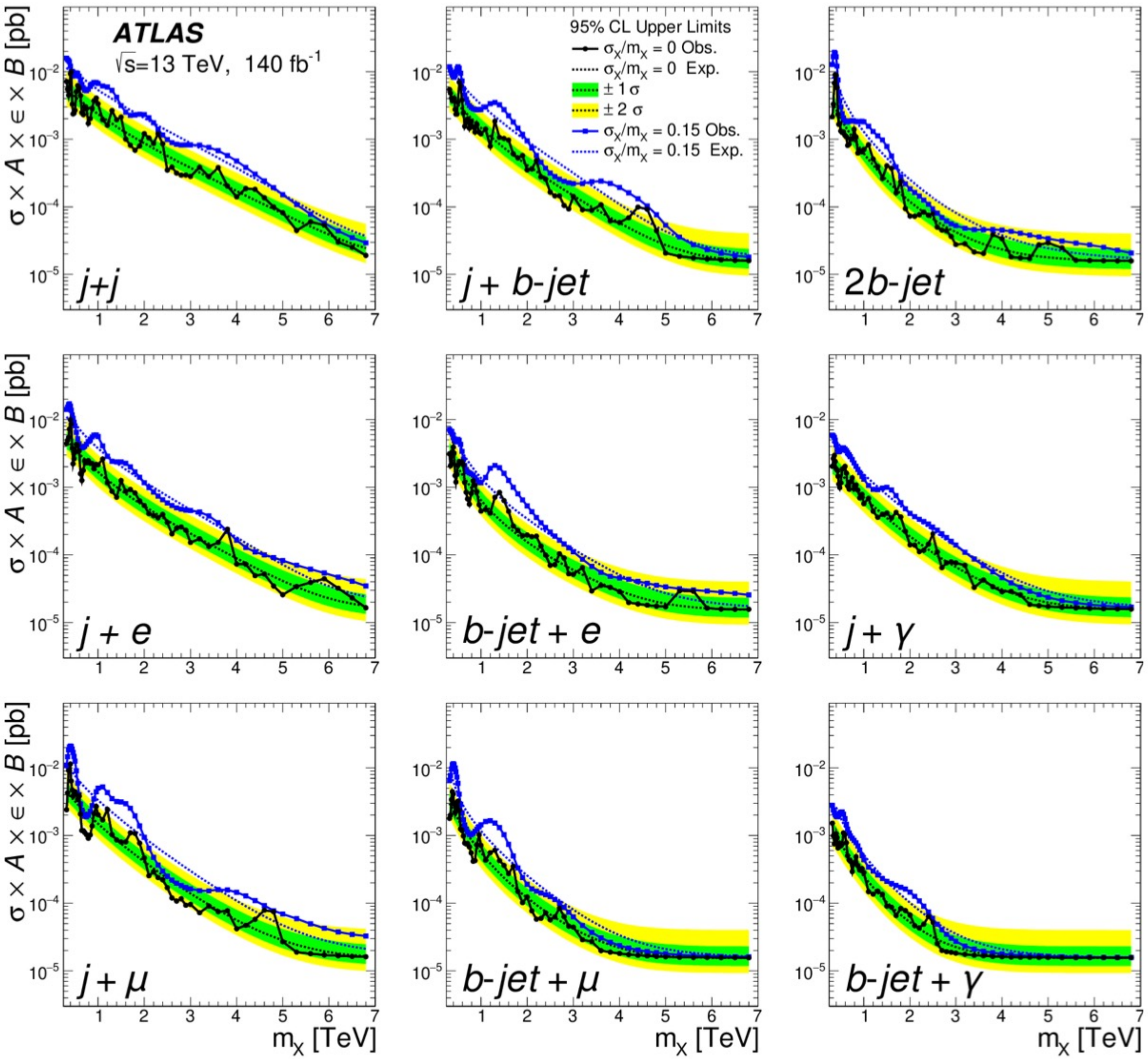


Fit invariant mass spectrum, statistical analysis, look for bumps



Upper limits of Gaussian signals

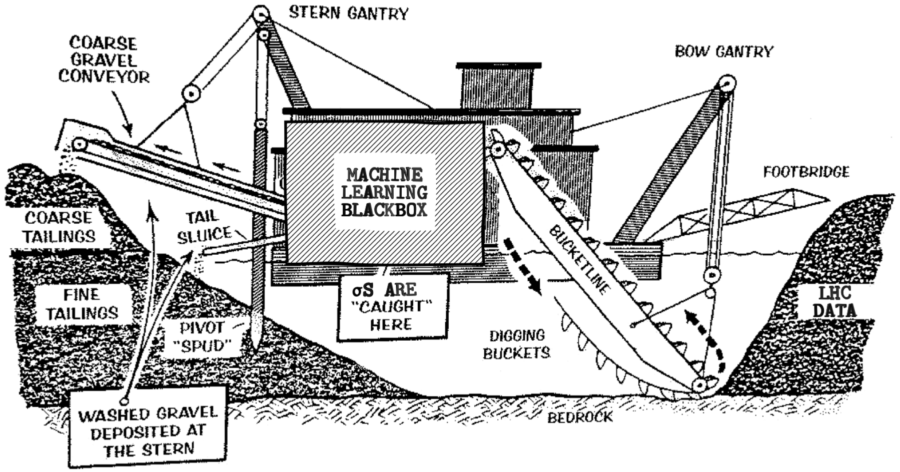
Rui Zhang

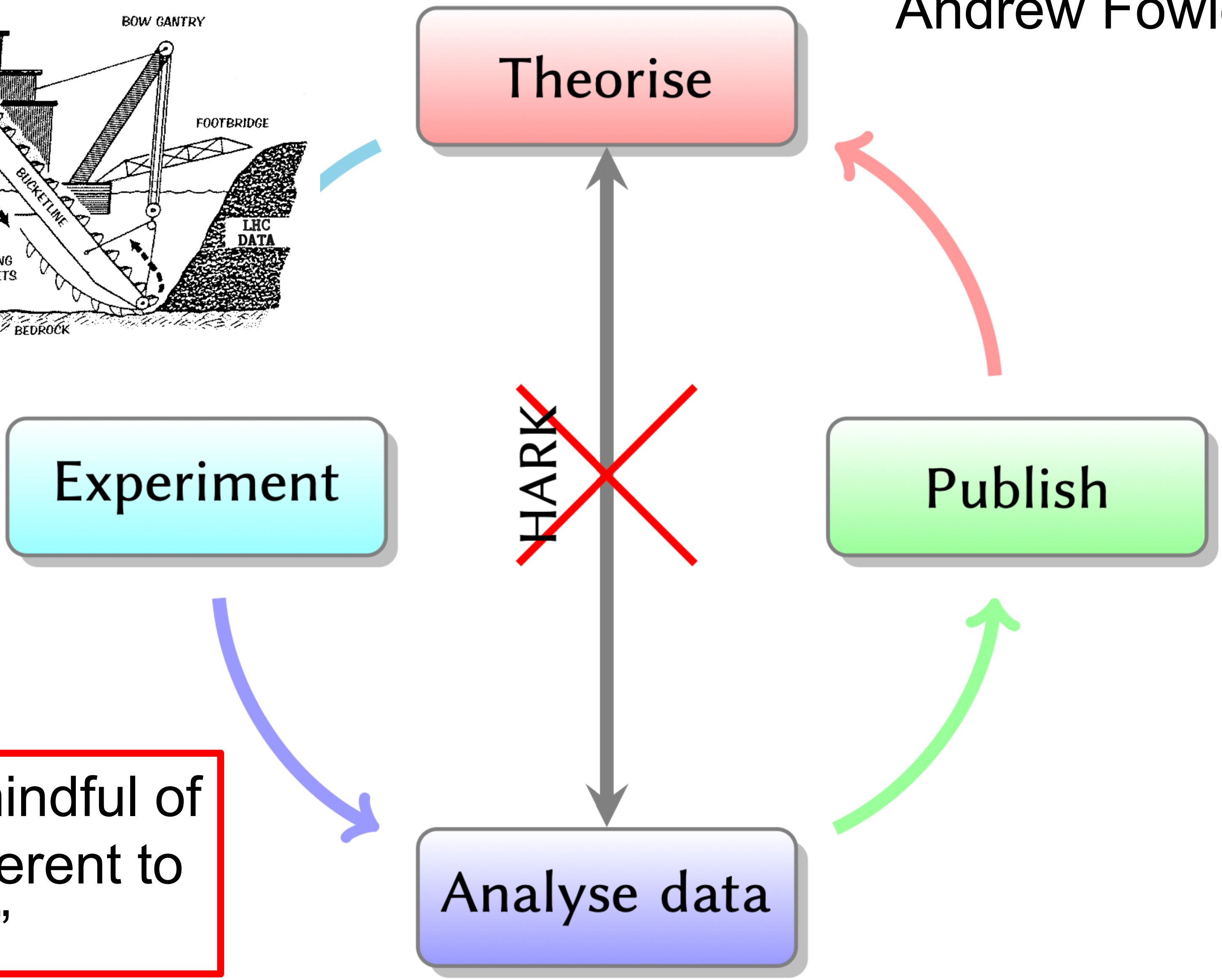


- Signal width of σ=0 and σ/m=15% are shown
  - Narrow signals have better limits as expected
- Error band is from σ=0
- Waves are similar, σ=0 is subject to local fluctuations
- Local 2.9 σ @ $m_{j\mu}$ = 4.8TeV, 2.8 σ @ $m_{j\mu}$ = 1.2TeV

HARKing = Hypothesising After Results Are Known

Andrew Fowley





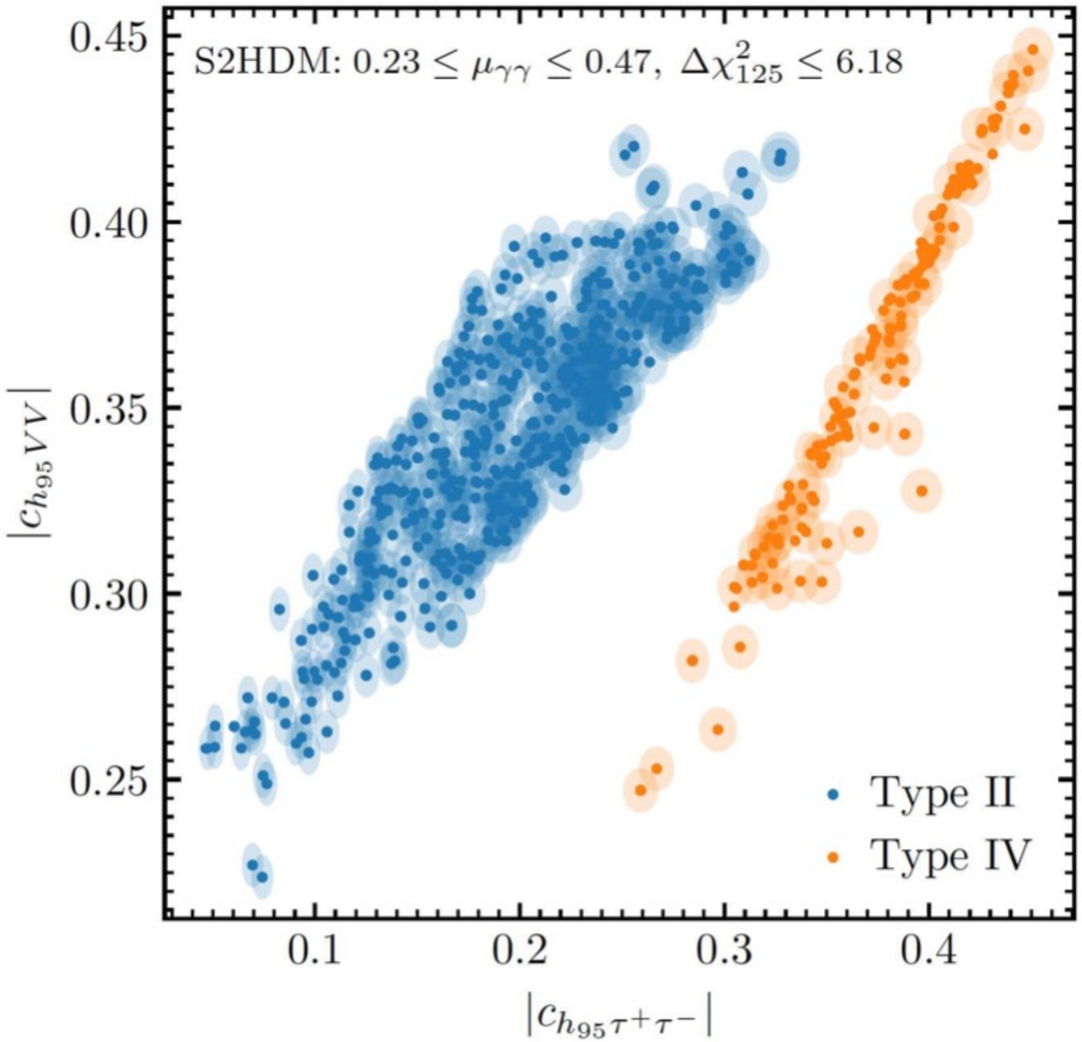
One has to be mindful of the features inherent to "Harking"

h_{95} coupling measurements at the HL-LHC/ILC

[T. Biekötter, S.H., G. Weiglein '23]

Sven Heinemeyer

Ellipses represent the 68% CL of individual measurements



$\Rightarrow$ models clearly distinguishable!